DRAFT STAFF REPORT

Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline

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This report assesses the vulnerability of San Francisco Bay and its shoreline to the impacts of climate change, identifies information needs for future vulnerability assessments, and suggests near-term and long-term strategies to address climate change impacts. Where feasible, those strategies are incorporated into recommended findings and policy revisions to the *San Francisco Bay Plan*. The preparation of this report was supported by a grant from the National Oceanographic Atmospheric Administration, Office of Coastal Resource Management.

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Special thanks to our intern Javier del Castillo for lending his expertise and time to sketch the typical shoreline cross-sections that appear throughout the report.

Executive Summary

A richly varied composite of urbanization and nature exists in and around San Francisco Bay. Urban waterfronts, critical habitat areas, industrial areas and residential neighborhoods coexist within walking distance of each other. Overlaid on these shoreline places is a vital system of public infrastructure, including freeways, seaports, railroads and airports, which knit the shoreline communities together and connect them to the rest of the region, California and the world. This tapestry helps make the beauty of the Bay Area world-renowned and underpins its economy, the health of its natural systems and the quality of life of its inhabitants. Over the past 150 years, the productive use of the Bay's shoreline has become the cornerstone of the region's prosperity and forged an inseparable bond between the people of the Bay Area and the Bay itself.

The nine-county San Francisco Bay Area is home to approximately seven million people making the Bay one of the world's most urbanized estuaries. Climate change has the potential to drastically alter lifestyles in the Bay Area. Such changes, along with new institutional priorities, are needed to reduce greenhouse gas emissions and moderate temperature increases attributed to global warming—to mitigate climate change. To some extent, the choice to alter lifestyles and institutional priorities now will reduce the degree to which the world must adapt to the effects of climate change. However, it is inevitable that over the next century global temperatures will increase 1° to 3° C (1.8° to 5.4° F). To deal with this increase in temperature, adapting to climate change and its impacts is both unavoidable and essential.

Global warming is expected to result in sea level rises in San Francisco Bay of 16 inches (40 cm) by mid-century and a 55 inches by the end of the century. The economic value of Bay Area shoreline development (buildings and their contents) at risk from a 55-inch rise in sea level is estimated at $62 billion—nearly double the estimated value of development vulnerable to sea level rise along California's Pacific Ocean coastline. An estimated 270,000 people in the Bay Area are at risk of flooding, 98 percent more than are currently at risk from flooding. In those areas where lives and property are not directly vulnerable, the secondary and cumulative impacts of sea level rise will affect public health, economic security and quality of life.

By mid-century, 180,000 acres of Bay shoreline are vulnerable to flooding, and 213,000 acres are vulnerable by the end of the century. The area that will be vulnerable to inundation with a 16-inch sea level rise at mid-century corresponds to today's 100-year floodplain. Extreme storm events will cause most of the shoreline damage from flooding. Changes in climate and sea level cause increase storm activity, which in combination with higher sea level, cause even greater flooding.

Local governments and land management agencies already face challenging issues, such as dealing with competing land uses, ensuring that adequate shoreline areas remain available for water-dependent uses, upgrading aged infrastructure, reducing traffic congestion, protecting habitat and water quality, maintaining flood protection, and providing public shoreline access. Shoreline vulnerability assessments can help government agencies and the public understand how existing planning and management challenges will be exacerbated by climate change and assist in developing strategies for dealing with these challenges.

Today's Big Flood is Tomorrow's High Tide

Two sea level rise estimates were selected for analysis in this report: a 16-inch (40 cm) sea level rise by mid-century and a 55-inch rise in sea level by the end of the century. Although the State of California is still in the process of formulating statewide policy direction for adapting to sea level rise, the estimates used in this report are generally consistent with other state planning efforts. At the same time, it is recognized that the range of sea level rise estimates used may not adequately reflect future additional sea level rise contributions from ice-sheet melt. Partly to deal with this problem the sea level rise estimates used in this analysis are based on higher greenhouse gas emissions scenarios. This approach is more risk-averse and better protects public safety because it will generate plans that will address conditions that are more extreme.

Using the chosen scenarios, the vulnerability assessment focused on three planning areas or systems: the shoreline environment, the Bay ecosystem, and governance. Key sectors within each system, such as land uses or subregions of the Bay, were used to assess their sensitivity, adaptive capacity and, ultimately, their vulnerability. Adaptation strategies were then developed to address key vulnerabilities.

The Shoreline

Residents, businesses and entire industries that currently thrive on the shoreline are subject to flooding by the middle of the century, and probably earlier. Shoreline development located in the current 100-year flood plain is subject to a 100 percent chance of flooding by mid-century. Approximately half of that development is residential, totaling 66,000 acres. Over 82,000 acres of residential development is vulnerable to flooding by the end of the century. Where residents are not directly vulnerable to flooding, access to important services such as commercial centers, health care, and schools would likely be impeded by flooding of the service centers or the transportation infrastructure that links them. Rising sea levels can impact the delivery of petroleum products, electricity, and drinking water to Bay Area residents and businesses. Dealing with this range of impacts will be more difficult for low-income residents because they have less financial flexibility and fewer resources to pursue alternative housing and transportation.

As temperatures increase, shoreline communities may experience a larger proportional increase in summer heat compared to inland communities, which can lead to heat stroke. Populations may also suffer if wastewater treatment is compromised by inundation from rising sea levels, a number of which discharge to the Bay. Compromised water quality and higher temperatures can result in algal blooms and a higher potential for the spread of water-born disease vectors.

Large commercial and industrial areas are vulnerable to flooding, especially in San Francisco, Silicon Valley, and Oakland. Approximately 72 percent of each of the San Francisco and Oakland Airports is vulnerable to a 16-inch sea level rise and 93 percent is vulnerable to 55 inches of sea level rise, which can disrupt the transport of as much as 30 million passengers and approximately one million metric tons of cargo. Flooding of highway segments in the regional transportation network can disrupt the movement of goods from ports, which handled approximately 25 millions metric tons of cargo in 2007-2008. Other water-related industries would be similarly affected. Flooding of the rail system would be particularly serious, since multiple users share a single line in most locations around the Bay.

The Bay is a magnificent body of water that helps sustain the economy of the western United States, provides great opportunities for recreation, nourishes fish and wildlife, affords scenic enjoyment and in countless other ways helps to enrich our lives. It is central to all most activities in the region, whether traveling by car or rail along the shoreline, landing at an airport, strolling along the shoreline, or watching the fog stream in on a summer's day. Waterfront parks and public access provide opportunities to enjoy the Bay and remind us of its place in the region. There are 23,000 acres of waterfront parks, of which 14 percent are vulnerable under the lower scenario and 18 percent vulnerable under the higher scenario. Fifty-seven percent of the public access required by BCDC is vulnerable under the low scenario and 87 percent vulnerable under the high scenario. The decline of waterfront recreational opportunities will impact the quality of life in the Bay Area.

To address the widespread flooding from storm activity and sea level rise, shoreline protection projects will be needed. Shoreline protection can be structural, natural, or a combination of both. Choosing the appropriate form of shoreline protection—one that both protects public safety and minimizes ecosystem impacts—is critically important. In the long-term, the region needs to engage in an open and vigorous public dialogue to make the difficult decisions about what to protect and where and what kind of new development is appropriate in vulnerable areas, and areas where further development should be avoided.

The Bay

The numerous plants and animals that inhabit the Bay provide many benefits to humans. For example, tidal wetlands provide critical flood protection, improve water quality, and sequester carbon. The brackish marshes in the North Bay and Suisun Marsh contain a great diversity of species and provide an important resting place along the Pacific Flyway. The impacts of climate change will substantially alter the Bay ecosystem by inundating or eroding wetlands and transitional habitats, altering species composition, changing freshwater inflow, and impairing water quality. Changes in salinity from reduced freshwater inflow affect fish, wildlife and other aquatic organisms in intertidal and subtidal habitats. The highly developed shoreline combined with reduced freshwater inflow constrains the natural adaptation mechanism of tidal marshes—to migrate upland—by reducing sediment and occupying open space to which marshes could otherwise migrate. The vulnerabilities from future climate change are further summarized in Table 3.1.

The Bay will continue to evolve in response to the climatic forces that enabled it to come into being. Historic modification of the ecosystem, through filling, diking, and building on the shoreline and reducing freshwater inflow, as well as ongoing stressors such as pollution and invasive species, have resulted in the decline of many native species and increased the vulnerability of surrounding communities to damaging floods. Substantial progress has been made in restoring the Bay ecosystem by returning diked areas to tidal action and reducing pollution, while efforts to increase freshwater inflow have been less successful. Future efforts to restore the Bay ecosystem can benefit from careful design that accounts for the known processes affecting formation of habitats in the Bay, the constraints imposed by existing stressors, and the future vulnerabilities.

Key questions that resource managers must address regarding climate change include: identifying opportunities for tidal wetlands and tidal flats to migrate landward, managing and maintaining adequate volumes of sediment for marsh sedimentation, developing and planning for natural flood protection, and maintaining sufficient upland buffer areas around tidal wetlands. Furthermore, habitats, like beaches, should be high priority for restoration and conservation.

Developing effective strategies to protect tidal wetland and tidal flat from sea level rise is extremely challenging because the projections of future sea level rise continually change. Since the 1980s, when widespread scientific concern about climate change and sea level rise emerged, projections for sea level rise have varied widely. This range of variation, based on different climate models and emission scenarios, creates a great deal of uncertainty for decision-makers, and therefore, wetland protection strategies must be adaptable to changing conditions.

Effective strategies should anticipate future desire to protect the shoreline from flooding using static or structural shoreline protection. Such protection requires long-term maintenance and can have unintended adverse impacts and, for these reasons, should not be seen as a long-term solution to flooding from sea level rise. Resilient shoreline protection, incorporating both engineering and ecosystem elements, should be used to present a balanced solution over the long term. Cumulative impacts of structural shoreline protection can have far reaching adverse impacts to the Bay ecosystem. Planning for sea level rise at a regional level can reduce those impacts and address difficult issues, such as the desire to provide shoreline protection on undeveloped shoreline. Where shoreline protection is necessary to protect development, it should be constructed to provide protection for a 100-year flood with the addition of 16-inches of sea level rise, at a minimum.

Governance

The Bay Area faces a range of vulnerabilities in its systems of governance that reduce the region's ability to adapt to sea level rise and other climate change impacts on the Bay and shoreline. A look at the region's overall governance system suggests that existing challenges to regional planning caused by the patchwork of federal, state, regional and local government authorities in the Bay region will be exacerbated by climate change impacts.

BCDC faces governance vulnerabilities in its laws and policies. The Commission's jurisdiction on the shoreline is limited to 100 feet from the Mean High Tide Line, and within this area BCDC's authority is limited to requiring maximum feasible public access and consistency with priority use areas. The Commission's law is based on principles in the Public Trust Doctrine, and the extent to which the public easement established by the Public Trust can move inland without "taking" private property is undetermined. Furthermore, because BCDC implements its authority on a permit-by-permit basis, the Commission is limited in its ability to address the cumulative impacts of individual shoreline protection projects. The existing framework of BCDC's laws and policies that focus on preventing the Bay from shrinking is an overarching constraint to the Commission's ability to effectively plan for and adapt to climate change impacts.

Local governments and other management agencies, especially in cities and counties, have broad authority over shoreline land use. However, they lack policy incentives, resources and regional guidance for addressing climate change impacts in land use planning. To address these gaps, local governments need information about the Bay-related impacts of climate change that is region-specific and site-specific. The information should include a regional model that projects 50-100 years into the future or the expected "life of a project." The projections should be developed through a public, inclusive process in order to be widely accepted and used throughout the region. The system most commonly used by local governments for analyzing information is GIS. However, local planners and resource managers can benefit from guidance documents, such as sample ordinances.

Lack of staff and adequate financial resources are the primary barriers to planning for impacts of climate change, both statewide and in the Bay Area. Any assistance to local governments and public management agencies must address this issue either by providing more staff and financial resources or by providing information that is easily integrated into existing operations, planning tools, guidance documents and planning processes (e.g., General Plan updates).

Adaptation

Adapting to climate change on the San Francisco Bay shoreline is critical to the region's economic stability, safety and public health. Flooding from sea level rise alone will impact long-term viability of our neighborhoods, job centers, transportation, water and wastewater infrastructure, schools and fire stations and vital ecosystem services on which our quality of life and the regional and state economies depend.

To integrate rapidly advancing scientific knowledge about the impacts of climate change, adaptation planning for the Bay and shoreline must be a flexible and iterative process. Shoreline planning will be increasingly challenging as the line between uplands and Baylands becomes more dynamic, thereby requiring a creative planning approach that integrates both the natural and the built environment. An ecosystem-based, adaptive management approach would integrate the human component of ecosystems into ecosystem management by bringing stakeholders into decision-making processes, promoting interagency collaboration, and providing direction through those processes.

Guidelines being developed in the state's adaptation planning process promise to be helpful in making difficult decisions about protecting the shoreline and dealing with proposed shoreline development in the Bay Area.

Adaptation Strategies

The first and most important adaptation strategy is to conduct a vulnerability analysis. Understanding vulnerability to the extent feasible within the limitations of available science and resources is critical to developing adaptation strategies. Vulnerability occurs over a long timeframe and affects people differently in the near-term and the long-term. Therefore, both short-term and long-term adaptation strategies should be identified.

In the long-term a variety of adaptation strategies involving many potential partners will be needed to deal effectively with sea level rise in the Bay Area. Some of these strategies can be initiated in the current update to the Bay Plan findings and policies (i.e., the strategy can be applied within BCDC's limited authority and jurisdiction). BCDC lacks the regulatory authority to begin implementing other strategies, but updated findings and policies that provide guidance relating to these strategies are appropriate for this Bay Plan update.

Strategies that the Commission can begin implementing immediately should be incorporated into the Bay Plan in the following manner:

1. Create a climate change policy section of the Bay Plan that addresses the following:
    a. Updating sea level rise scenarios and using them in the permitting process;
    b. Developing a long-term strategy to address sea level rise and storm activity and other Bay-related impacts of climate change in a way that protects the shoreline and the Bay; and
    c. Working with the Joint Policy Committee (JPC) and other agencies to integrate regionally mitigation and adaptation strategies and adaptation responses of multiple government agencies, to analyze and support environmental justice issues, and to support research that provides useful climate change information and tools.
2. Amend findings and policies on public access to provide public access that is sited, designed and managed to avoid significant adverse impacts from sea level rise and ensures long-term maintenance of public access areas.
3. Amend findings and policies on tidal marshes and tidal flats to ensure that buffer zones are incorporated into restoration projects where feasible and sediment issues related to sustaining tidal marshes are addressed.
4. Amend the policies on safety of fills by updating the findings and policies on sea level rise and moving them to the new climate change section of the Bay Plan.
5. Amend the policies on shoreline protection to address protection from future flooding.

CHAPTER 1

CAUSES OF SEA LEVEL RISE

Greenhouse gas (GHG) emissions have already contributed to an increase in average global temperature and may trigger irreversible impacts from continued global warming. A rise in global temperature is expected to be accompanied by other climatic changes and impacts, such as increased frequency of temperature extremes; changes in precipitation patterns; reduced soil moisture content; melting of polar ice caps, land-based ice sheets and glaciers; ocean warming and consequent changes in sea level and water circulation. Detrimental impacts to ecosystems will likely affect public health and the economy. This chapter explains the causes of climate change, the United Nations Intergovernmental Panel on Climate Change (IPCC) scenarios, the California Climate Action Team's scenarios, and the Bay Area's contributions to and efforts to mitigate GHG emissions. It further explains the causes of sea level rise, increased storm activity, and sea level rise scenarios that should be used to minimize risks on the shoreline. Finally, this chapter describes the approach to the vulnerability assessment Chapters 2-4 and discusses shoreline protection options.

The Greenhouse Effect and Global Warming

The "greenhouse effect" is a natural system that controls the Earth's temperature. Water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), residing in the Earth's atmosphere, absorb heat emitted from the Earth's surface and radiate heat back to the surface. The Earth's surface temperature would be about 61°F (34°C) colder than it is now without this natural heat trapping system (CAT 2006).

The Earth's climate is dynamic and constantly changing. However, recent observations and modeling indicate that the rate and magnitude of change occurring today is unprecedented for the most recent geologic period (the Quaternary period or last 2 million years). Ice core samples provide information about historic concentrations of GHGs and provide information about human contributions to global climate change. Concentrations of CO_2 in the samples correlate to recent observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. The IPCC reported in its Fourth Assessment Report (AR4) that the current observed global average temperature increase is about 2.2°F (0.2 °C) per decade (IPCC 2007).

There are both human and natural causes of climate change. Changes that alter the climate system, such as changes in the amount of GHGs in the atmosphere, in solar radiation, and in land surface, are called "radiative forcings." These are studied to compare how a range of human and natural factors cause warming or cooling (IPCC 2007). The IPCC AR4 examined radiative forcings from human and natural factors and concluded that: (1) it is extremely unlikely that global climate change of the past 50 years can be explained without human contributions of GHGs; (2) carbon dioxide is the most important human contribution to greenhouse gases; and (3) the primary source of the increased CO_2 is from fossil fuel use with land-use change as another significant, but smaller contribution. There is a broad consensus in the scientific community that climate change is real and the release of GHGs caused by human activities is accelerating this change.

Emissions Scenarios. While scientists agree that the planet is warming, the amount and timing of this change is less certain and likely will remain so for some time. In order to predict future climate change it is necessary to know how much GHGs will be produced in the future. It is difficult to predict future GHG emissions without knowing how global development will proceed. The IPCC addressed this uncertainty by developing future global development scenarios, which are included in a Special Report on Emissions Scenarios (SRES). For each SRES, the key activities that influence global development rates were altered to produce a range of future development patterns. Specific variables, such as population, economic growth, technological change, resource availability, and land-use changes were considered in order to quantify GHG emissions relative to each scenario (IPCC 2000). Four SRES were developed to cover a wide range of variables: the A1 scenario breaks into four sub-scenarios, one of which (A1FI) has the highest emissions of all the scenarios; the A2 scenario also has high emissions; B1 has the lowest emissions; and B2 is a middle-range emissions scenario.

The SRES was published in 2000 and the scenarios continue to be widely used in assessments of future climate change. In AR4, a warming of about 0.36° F (0.2° C) per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols (small particles in the atmosphere that absorb and scatter radiation, such as smoke or dust) were kept constant at 2000 levels, a further warming of about 0.2°F (0.1°C) per decade would be expected (IPCC 2007). The projected global temperature increase at the end of the century in the range of SRES is between 3.2° F and 6.8° F (1.8° C and 3.8° C) (Table 1.1). Mitigating or reducing GHG emissions is critical to slow climate change, but mitigation will not stop changes that are already underway. Therefore, adapting to climate change is equally critical as mitigating climate change.

Table 1.1. Projected Global Average Surface Warming at the End of the Century

Scenario	Temperature Change (Degrees at 2090-2099 relative to 1980-1999)			
	Best Estimate		Likely Range	
	°F	°C	°F	°C
Constant year 2000 concentrations	1.1	0.6	0.5 – 1.6	0.3-0.9
B1	3.2	1.8	2.0 – 5.2	1.1 - 2.9
B2	4.3	2.4	2.5 – 6.8	1.4 – 3.8
A2	6.1	3.4	3.6 – 9.72	2.0 – 5.4
A1FI	6.8	3.8	4.3 – 11.5	2.4 – 6.4

Adapted from IPCC 2007.

The California Climate Action Team. While the IPCC assessments of climate change rely on global models, adapting to climate change requires an understanding of how climate change will impact specific regions so that planning can take place at the state and regional levels. The California Climate Action Team (CAT) relies on the SRES for assessing the primary impacts of climate change on a regional level, namely changes in the frequency and intensity of precipitation and temperature increases (Cayan et. al. 2006 and Cayan et. al. 2008(b)).

In its 2009 climate change research, the CAT chose two IPCC scenarios to report on climate change impacts in California: A2 (a higher emissions scenario) and B1 (a medium-low scenario). Researchers used the A2 and B1 scenarios to run multiple global climate computer models and performed additional research to project specific climate changes in California (Cayan et. al. 2008(b)).

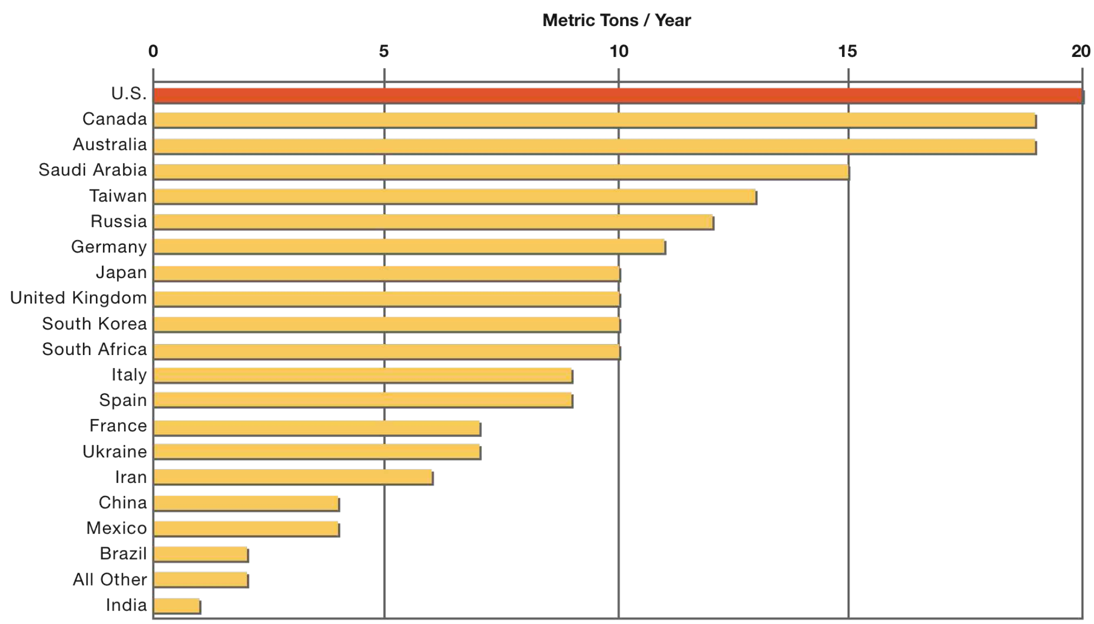
The CAT projects that temperatures will get higher in the inland areas of California than on the coast. Overall, the projected warming is consistent with IPCC projections: between 1.8°F and 5.4°F (1°C and 3°C) by mid century and between 3.6°F and 9°F (2°C and 5°C) by the end of the century (Cayan et. al. 2008(b)). Temperature increases in the lower range of warming are projected to be similar to the difference in average annual temperature between Monterey and Salinas. In the upper range of projected warming, the temperature difference would be closer to that between San Francisco and San Jose (Cayan et. al. 2006).

The CAT findings regarding precipitation were similar to findings for the globe, with a tendency toward drier conditions at the end of the century (Cayan et. al. 2008(b)). Generally, even small changes in precipitation can be problematic for California because ecosystems are "conditioned to historic precipitation levels and water resources are nearly fully used" (Cayan et. al. 2006). Furthermore, about one third of California's water currently falls as snow in the Sierra Nevada Mountains and much of the water stored in the Sierra snowpack and reservoirs is used in the Central Valley, the Bay Area and Southern California during the spring and summer. As temperatures rise, the snowpack will melt earlier and less precipitation might fall as snow, further hampering California's ability to store enough water and provide it to agricultural fields and growing populations. As the primary catchment basin for the Sierra Nevada watershed, changes in the amount of fresh water that flows to the Bay from the Sierra directly affects the Bay ecosystem.

As an example of the scope of the impacts within one economic sector, California's $30 billion agriculture industry currently uses almost 80 percent of developed water in the state (DWR 2006). However, in addition to adverse impacts stemming from changes in the state's water management system, some of the state's most lucrative crops, such as wine grapes, fruits and nuts could falter under higher temperatures. Furthermore, high temperatures can stress dairy cows severely hampering what is currently a $3 billion industry.

Figure 1.1 U.S. Contribution To Global CO_2 Emissions (per Capita)

Source: U.S. Energy Information Administration; Bay Area Air Quality Management District, 2007



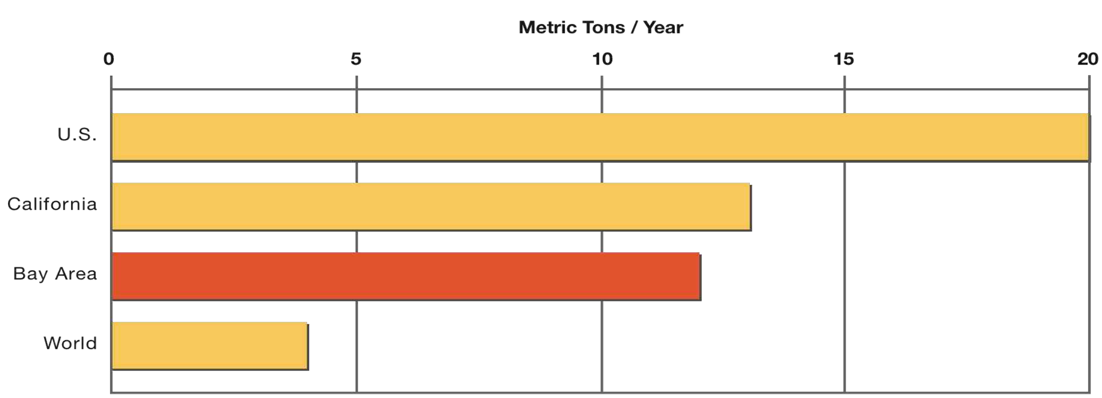
With so much at risk for California, on June 1, 2005, the Governor issued an Executive Order establishing GHG emission targets for the state. California strengthened its commitment to address climate change with the passage of Assembly Bill 32 (AB 32), the Global Warming Solutions Act of 2006. AB 32 requires the state to reduce GHG emissions to 1990 levels by 2020 and to 80 percent below 1990 levels by 2050 (CARB 2008).

On August 25, 2008, the State Assembly passed SB 375 and the Governor signed it into law on September 30th, 2008. The bill mandates an integrated regional land-use-and-transportation-planning approach to reducing greenhouse-gas (GHG) emissions from automobiles and light trucks, principally by reducing vehicle miles traveled (VMT). Within the Bay Area, the bill assigns responsibilities to the Association of Bay Area Governments (ABAG) and to the Metropolitan Transportation Commission (MTC). Both agencies are members of the Joint Policy Committee (JPC), which also includes the Bay Area Air Quality Management District and BCDC. The JPC developed a policy document to guide ABAG and MTC in fulfilling their responsibilities in collaboration with their JPC partners (JPC 2009).

Bay Area GHG Contributions. The Bay Area is a major contributor of GHG emissions. In order to understand how the Bay Area fits into the global emissions scheme, some context is necessary. The United States produces more CO_2 emissions per capita than any other country in the world and twice the emissions of most “developed” countries (Figure 1.1). California is the twelfth largest source of climate change pollutants in the world, ranked between South Korea and Italy, and emits more GHGs than most nations. When CO_2 is measured in per capita metric tons/year, the Bay Area is only slightly below the statewide average (Figure 1.2).

Figure 1.2 Bay Area Contribution to CO_2 Emissions (per Capita)

Source: USEIA, CA Climate Action Team, BAAQMD; Bay Area Air Quality Management District, 2007

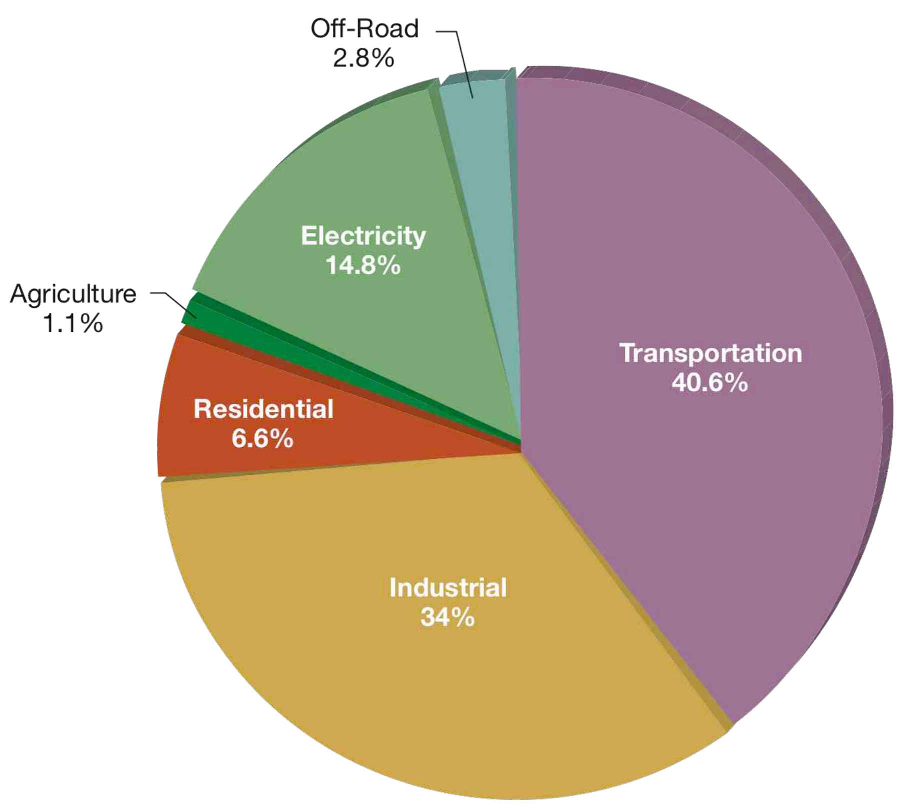


California's climate change emissions come primarily from fossil fuel combustion in the transportation sector, which makes up 41.2 percent of the state's GHG emissions. Energy production and industrial uses are other major contributors.

The Bay Area Air Quality Management District reports the Bay Area breakdown of climate change emissions is similar to the statewide breakdown. The two sectors with the highest emissions are transportation and industrial, which make up 40 and 34 percent of the total GHG emissions respectively (Figure 1.3).

Figure 1.3 Bay Area GHG Sources

Source: BAAQMD, 2007



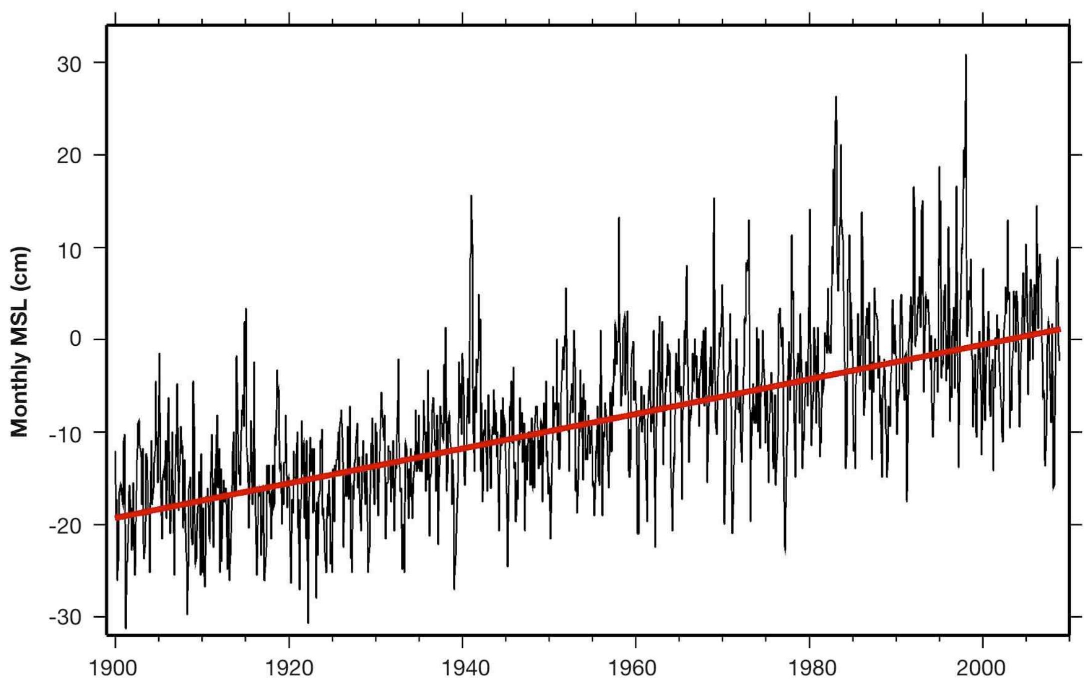
The regional Joint Policy Committee (JPC) developed a strategy to address climate change, which reflects the diverse responsibilities of the four regional agencies that make up the JPC. Those are, the Bay Area Air Quality Management District, the Association of Bay Area Governments, the Metropolitan Transportation Committee, and BCDC. Given that transportation is the primary source of GHG emissions in the Bay Area, the JPC's climate change strategy includes numerous objectives aimed at reducing driving through a variety of methods, including focused growth and transit oriented development and public transportation funding strategies, which all reduce the need to drive. BCDC is responsible for carrying out the elements of the strategy that address adapting to sea level rise and other Bay-related impacts of climate change.

Sea Level Rise

Warming of the planet causes sea level to rise and increases the potential for damaging floods that will affect coastal communities around the world. There are two major processes that contribute to global mean sea level rise, primarily by increasing the volume of water in the global ocean. Those processes are: (1) the addition of water from land-based ice and ice sheets (Bindoff et.al. 2007); and (2) thermal expansion, which is when water expands as it warms, causing sea level to rise. These processes are complex and difficult to project into the future. While the melting of sea-based ice (e.g., polar ice caps and icebergs) has significant adverse environmental impacts, it does not contribute additional water to the oceans and, therefore, does not directly contribute to global sea level rise.

Figure 1.4 Sea Level Rise in San Francisco Bay

Source: Cayan et. al. 2006; San Francisco Tide Gauge

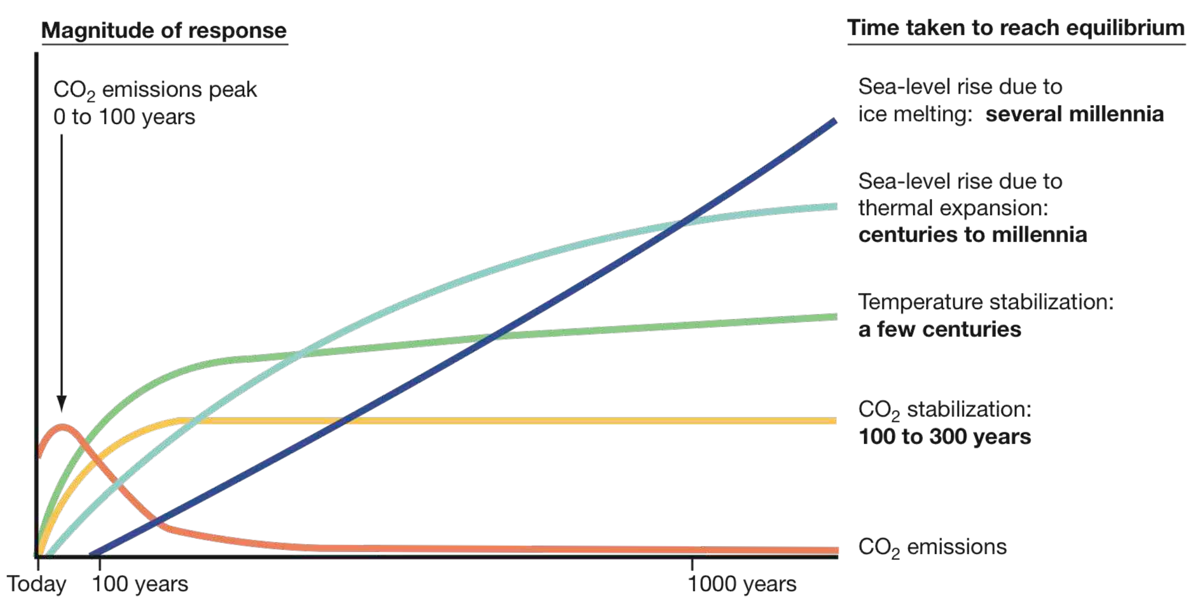


The San Francisco tide gauge at Fort Point is the longest continually monitored gauge in the United States. Sea level rise trends measured at this tide gauge and two other long-running tide gauges on the west coast show sea level rise of nearly 7.9 inches (20 cm) per century or 0.08 inches (2 mm) per year (Figure 1.4) (Cayan et. al. 2006). This rate of sea level rise is consistent with global sea level rise.

The rate of global sea level rise is increasing. The 20th century rise was estimated to be 6.7 inches (17 cm) or 0.067 inches (1.7 mm) per year on average. From 1961 to 2003, GHG emissions had been accumulating long enough to increase the rate of rise to 0.07 inches (1.8 mm) per year (IPCC 2007). Analyses of observed sea level rise over the last approximately 15 years show that the rate of rise increased significantly above that of previous decades (Church and White 2006). The IPCC concluded that from 1993-2003, the rate of sea level rise increased to about 0.12 inches (3.1 mm) per year (IPCC 2007), demonstrating the likely effect of human-induced warming on sea level.

Figure 1.5 Long Term Trend in Sea Level Rise

Source: Intergovernmental Panel on Climate Change; Department of Water Resource, based on IPCC



No matter how effectively the world mitigates GHG emissions, oceans have already warmed, sea levels are already rising at accelerated rates, and are likely to continue rising. The ocean has been absorbing more than 80 percent of the heat added to the climate system and has already warmed to depths of at least 9,843 feet (3000 m) (IPCC 2007). Perhaps the most notable finding from the IPCC is that the effects of GHG emissions will continue long after emissions are reduced. The IPCC projects that temperature increases continue for a few centuries before temperatures stabilize. Sea level rise from thermal expansion continues for centuries to millennia. Sea level rise from ice-sheet melting continues for several millennia (Figure 1.5) (IPCC 2007).

Ice-Sheet Melting and Uncertainty. There is a great deal of uncertainty surrounding the future contributions to global sea level rise from the melting of the Greenland and Antarctic ice sheets. Most scientists agree that the rate of ice-sheet melt will accelerate as melt-water seeps through cracks in the ice sheet and causes further acceleration of melting and movement of the ice sheet toward the sea. The IPCC concluded that losses from the ice sheets have "very likely" contributed to sea level rise from 1993 to 2003. (In IPCC terminology, very likely means a greater than 90 percent probability of occurring.) However, there is no scientific consensus on how to model or project future rates of ice-sheet melt.

The nature of ice-sheet melt is not fully understood. Observations show that as ice melts, the melt water runs over ice and causes it to melt at a faster rate, carving deep crevices and weakening the ice. Further, the meltwater runs under the ice sheets and weakens buttressing ice shelves, which can cause large portions of ice sheets to collapse. The central question is whether ice-sheet melting will accelerate by an order of magnitude and whether this could occur in a timeframe of hundreds or thousands of years (Oppenheimer 2006).

Warming of 3.6-5.4° F (2-3° C) could cause melting that would induce "multiple positive feedbacks, including reduced surface albedo, loss of buttressing ice shelves, [and] dynamical response of ice streams to increased melt-water" (Hansen 2006). Surface albedo is a ratio of incoming radiation that is reflected to that which is absorbed. White ice has a high albedo—it reflects most solar radiation, which means that as sea-ice melts, the oceans absorb more heat from radiation. Due to these feedback effects, some scientists believe that the ice sheet response could move beyond a point of equilibrium within a few centuries (Hansen 2006). However, even with ice-sheet melt, sea level rise is very unlikely to exceed 6.6 feet (200 cm) by 2100 (Pfeffer et. al. 2008).

Although numerical modeling remains inadequate to project future ice-sheet melt, additional studies of the last interglacial period confirm that the warming needed to cause shrinkage of the Greenland Ice Sheet averaged less than 6.3° F (3.5° C) (Overpeck et. al. 2006). Further, recent observations and innovations have improved modeling of ice-sheet behavior, but models still do not assess feedback loops and, therefore, fail to factor the interrelatedness of ice-sheet melting, ocean circulation, and climate change (Alley et. al. 2005). The AR4 projections for warming in the years 2090-2099 ranged from 3.2° F (1.8° C) for the lowest emissions scenario (B1) to 7.2° F (4° C) for the highest emissions scenario (A1FI). Therefore, mid and higher emissions scenarios produce temperature increases by the end of the century that would, at a minimum accelerate ice-sheet melt.

Sea Level Rise Scenarios

There is broad scientific consensus that the rate of sea level rise has increased with higher global surface temperatures. The point of debate is what the rate of sea level rise will be in the future. Similar to the approach used to evaluate global warming, using scenarios of future sea level rise enable us to understand the risks and develop a strategy that will support the appropriate responses. Scenarios of future sea level rise enable us to understand the risks and develop a framework now that will support the appropriate responses.

In 2007, German scientist, Stefan Rahmstorf developed an empirical approach to projecting future sea level rise by calculating the relationship between sea level rise and global mean surface temperature. Rahmstorf first determined the historic trend in the relationship and then projected that trend into the future using the IPCC's projected temperature increases associated with the SRES scenarios: 2.5°F (1.4° C) for the lowest emissions scenario to 10.4° F (5.8° C) for the highest emissions scenario (Rahmstorf 2007). Rahmstorf's corresponding estimates of sea level rise by 2100 range from 10 inches (50 cm) to 55 inches (140 cm) respectively.

Research funded by the CAT for the 2009 report to the Governor used the A2 and B1 scenarios and Rahmstorf's methodology to project sea level rise in 2050 and 2099. These sea level rise projections are also adjusted to include the effects of dams on sea level rise (Cayan et. al. 2008(b)). Past construction of dams and reservoirs may have stored enough water worldwide to mask acceleration in the rate of sea level rise prior to the notable acceleration detected in 1993. Most dams were constructed during the 1950s through the 1970s. Building of dams for additional upland water storage has since slowed, which means that sea level rise may now be accelerating faster than the IPCC and scientists have predicted (Chao 2008). The CAT-funded research estimates that sea level will increase between 12 and 17 inches (30 and 45 cm) by 2050 and between 20 and 55 inches (50 and 140 cm) by 2099 (Table 1.2).

Table 1.2. CAT Sea Level Rise Scenarios

Emissions Scenario	Increase in Sea Level From 2000-2050	Increase in Sea Level From 2000-2099
Lower (B1)	12 in (30 cm)	20 in (50 cm)
Higher (A2)	17 in (45 cm)	55 in (140 cm)

The Delta Vision Blue Ribbon Task Force established by Governor Schwarzenegger to develop a strategic management plan for the California Delta, employed an Independent Science Board (ISB) to review literature and provide recommendations on sea level rise. The ISB found that: (1) the current IPCC projections are conservative and underestimate recently measured SLR; (2) empirical models, such as Rahmstorf's empirical method, yield significantly higher estimates of sea level over next few decades and are better for short to mid-term planning; and (3) neither the IPCC or Rahmstorf account for accelerating contributions from ice sheet melting, which will likely contribute significantly to future sea level rise with the potential for very rapid increases of up to a meter by 2100. Based on these findings, the ISB recommended adopting an estimated rise in sea level of 55 inches (140 cm) by 2100 and recommended adopting a sea level rise estimate for 2050 as well.

Sea Level Rise and Extreme Events. Most shoreline damage from flooding will occur as a result of storm activity in combination with higher sea level. Climate change-induced sea level rise will change the key factors that contribute to coastal flooding: tide heights, storm surge, river flows released from major reservoirs in the Sacramento and San Joaquin watersheds, and wind-waves (Gleick, 1990, Cayan et. al. 2008(a), BCDC, 2007).

Storms and flooding in California occur during the winter from November to April and are influenced by several climate patterns, most prominently the El Nino Southern Oscillation (Miller 2003, Cayan et. al. 2008(a)). Every two to seven years, ENSO alternates between two phases, La Nina and El Nino. In contrast to La Nina, "El Nino years" generally result in persistently low air pressure, greater rainfall, and dominantly western winds (Cayan et. al. 2008(a)), all of which contribute greatly to coastal flooding hazards.

Low air pressure causes an instantaneous rise in sea level above predicted tides, referred to as storm surge (Cayan et. al 2008). During storms with high rainfall, Bay tributaries flood, elevating Bay waters beyond the initial storm surge, and low air pressure increases wind activity, generating erosive waves superimposed on the already high sea levels (Bromirski and Flick 2008). This combination of factors, during an El Nino event in the winter of 1982-83, caused over $500 million in damage in the San Francisco Bay Area (ABAG 2006).

When storm surge occurs on higher sea level, floods will become increasingly hazardous to public health and safety and will likely occur more frequently. Over the recent period of accelerated sea level rise (1993 to 2003), there was an increase in both the number of storm surge events and high tides exceeding previously observed extremes. This increase in storm activity and extreme tides is projected to continue into the future (Cayan et. al. 2008(a), Bromirski and Flick 2008). Should the state's water reservoirs lack capacity to capture rainfall and earlier Sierra snow melt, water managers will need to release flows through the Delta during Winter months, resulting in even higher water levels (Knowles and Cayan 2002).

Different regions of the Bay may be more vulnerable to these floods than others (see Figure 1.6 for Bay regions). Tides in the South Bay are higher than the ocean and other areas of the Bay, which will amplify storm surge events (PWA 2005). The combined effects of sea level rise, storm surge and river flooding may result in water levels elevated as high as 51 inches for a period of 10 to 12 hours in the Delta and Suisun Marsh region (Bromirski and Flick 2008), an area already below mean tide elevation surrounded by fragile levees (DWR and DFG, 2008).

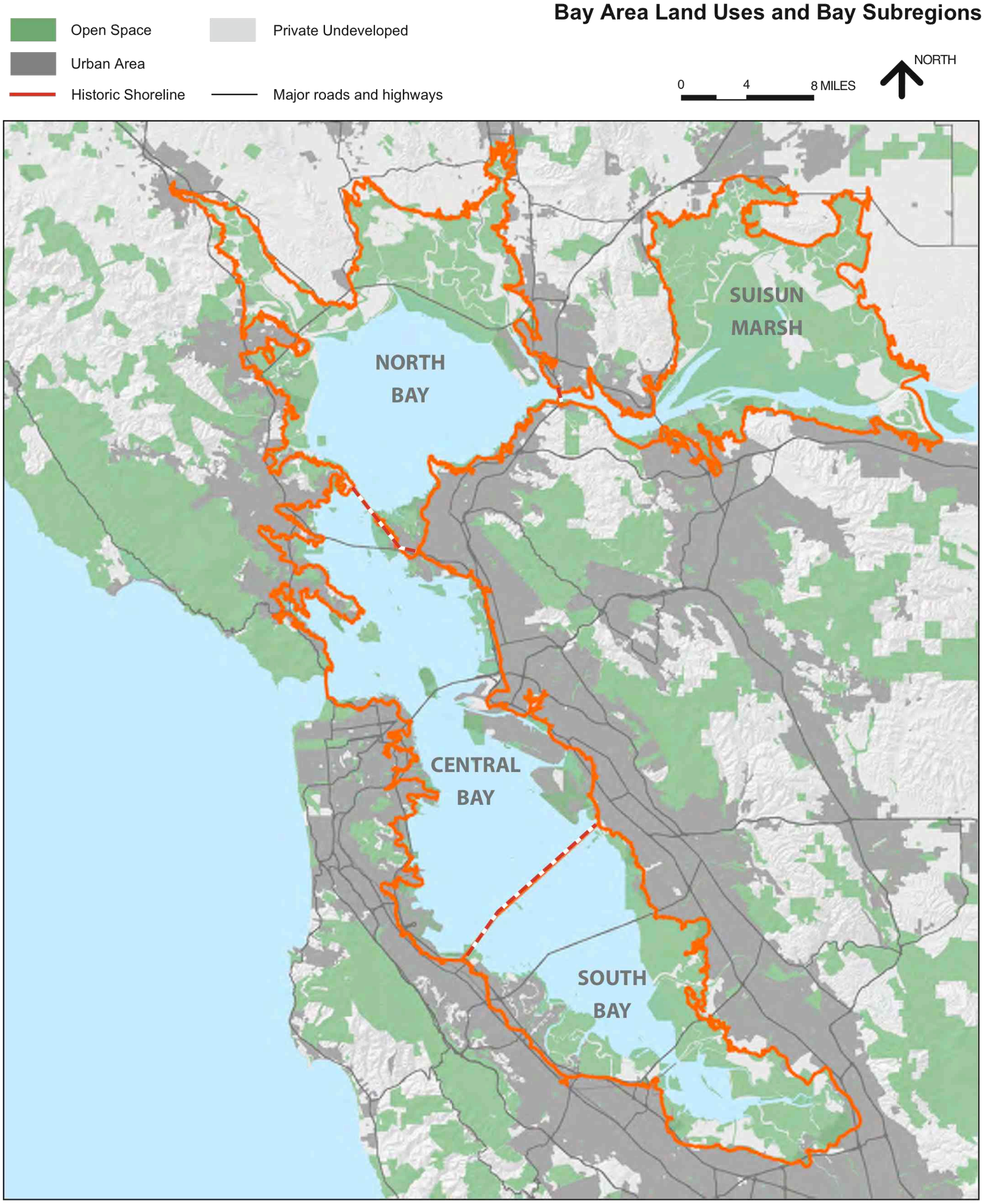
Therefore, significant flooding impacts from sea level rise can be expected during the early part of this century due to winter storms and sea level rise.

BCDC Scenarios. When evaluating a permit application for a project proposal, it is reasonable to assume that most projects will have a lifespan of at least 50 – 90 years. For the purposes of this policy analysis and to provide timeframes that are most relevant to the Commission's regulatory and planning functions, a mid-century and end-of-century planning estimate are used. The shorter timeframe is most applicable for projects such as, residential or commercial development. The longer timeframe attempts to anticipate future impacts within a reasonable degree of certainty for large-scale projects with longer life cycles, such as major public infrastructure projects. While these are only scenarios, not predictions, the necessary response to rising sea level may be similar whether sea level rises more slowly or more quickly, The primary difference will be in the scale and speed of response that will be required.

On November 14, 2008, the Governor issued Executive Order S-13-08 directing state agencies to plan for sea level rise. In particular, the California Natural Resources Agency was directed to develop a statewide adaptation strategy. Since the Executive Order was issued, state CAT-funded sea level rise assessments have used 16 inches and 55 inches of sea level rise to analyze the statewide impacts.

Figure 1.6

Bay Area Land Uses and Bay Subregions



SOURCE: Urban and open space (GreenInfo 2004), Regions (EcoAtlas 2009)

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This report assess vulnerability using 16 inches of sea level rise at mid-century and 55 inches at the end of the century because: (1) given the potential for sea level rise to threaten lives and damage property and natural resources in the Bay, it is imperative to use a risk-averse scenario; and (2) it is consistent with other state efforts. A number of terms that are common in discussions of adaptation are defined in Box 1.1.

> **Box 1.1. Definitions**
>
> **Resilience:** The ability of a system to absorb and rebound from the impacts from weather extremes, climate variability, or change and to continue functioning (Luers and Moser)
>
> **Adaptation:** Actions in response to potential or experienced impacts of climate change that lead to a reduction in risks or a realization of benefits.
>
> **Mitigation:** Actions that reduce the emission of greenhouse gases into the atmosphere or enhance their sequestration and thereby reduce the probability of reaching a given level of climate change.
>
> **Vulnerability:** The extent to which a natural or social system is susceptible to the adverse effects of climate change, climate variability and extremes—a function of risk and adaptive capacity.
>
> **Adaptive Capacity:** The ability of a system to adjust or respond to climate change, climate variability and extremes, to accomplish the following: (1) moderate potential damages; (2) take advantage of new opportunities arising from climate change; or (3) accommodate the impacts.

Vulnerability Assessment

The following three chapters describe the vulnerability assessment performed for this report. The assessment is both qualitative and quantitative, including a review of literature and original analysis using GIS sea level rise data. It focuses on three planning areas or systems: the shoreline environment, the Bay ecosystem, and governance. Key sectors within each system are identified and analyzed to ascertain their current and expected challenges and projected climate change impacts. Based on the information available, which in some cases is limited, and recognizing the general uncertainty involved in projecting climate change impacts, a vulnerability assessment is performed that identifies the degree of sensitivity, adaptive capacity, and vulnerability. This assessment is summarized at the end of each chapter based on a standard methodology developed through The Climate Project for King County in Washington (The Climate Project 2007).

The emphasis of this assessment is regional, which may limit its application to specific projects or limited areas, such as the shoreline within any given city. While the assessment is valuable, it is limited by the information available and the uncertainty regarding future change. To make the assessment feasible, BCDC worked with the California Energy Commission's Public Interest in Energy Research (PIER) program to commission the development of sea level rise data and a cost assessment of potential impacts from sea level rise.

The sea level rise data were provided by the United States Geologic Survey (USGS), which used a hydrodynamic computer model to identify areas at risk of sea level rise scenarios. The USGS assembled the best available elevation data for the Bay shoreline into a regional grid. Historic (1996-2007) tidal data were used to determine the highest average monthly tide, then the sea level rise estimates were integrated into the tidal datum (Knowles 2008)[1].

While the data are the best available for mapping and analysis of shoreline areas that are vulnerable to sea level rise, there are limitations for their use. The data were developed using an average of the highest tide in each month, which captures most storm surge within a year. However, the data do not include wave activity that occurs during storms. Consequently, an area that floods from wave activity during winter storms, such as the Embarcadero in San Francisco, is not counted as vulnerable. Importantly, where the elevation of land is below the water level, it is shown as vulnerable, whether or not shoreline protection exists. This is because adequate information was not available on levee heights or strength. Low-lying land located inland or depressions in upland areas may also appear vulnerable, even without a path for water to reach the isolated, low-lying area. Even without this information, the data is reliable for drawing important conclusions about the region's vulnerability to sea level rise and storm surge.

Analysis using the data shows that approximately 180,000 (281 square miles) of shoreline are vulnerable to flooding with 16 inches (40 cm) of sea level rise and approximately 213,000 acres (332 square miles) are vulnerable at 55 inches (140 cm). When the areas of vulnerability are mapped (Figures 1.7-1.18), it is clear that most of the flooding occurs under the 16-inch scenario, by mid-century. With 55 inches of sea level rise, the additional 33,000 acres (51 square miles) of vulnerable area is scattered around the perimeter of the area that is vulnerable under the lower scenario.

The area inundated in the 16-inch scenario is already subject to some degree of vulnerability. The topography of the Bay shoreline is such that the area inundated under the lower scenario is largely the same as the 100-year flood plain (Figure 1.19). A 100-year flood is a flood that is predicted to occur, on average, once every 100 years and so has a one percent

---

[1] The data for this assessment was developed by USGS analyzing the area vulnerable to inundation from the average highest monthly tide, factoring in 16 and 55 inches (40 and 140 cm) of sea level rise. The data used by Knowles and the Pacific Institute in two recent reports on sea level rise in San Francisco Bay are based on an average highest yearly tide, factoring in the same two scenarios. However, the difference between these data is insignificant. although the average yearly high tide inundates an area approximately 1% (2,000 acres) greater than the average monthly high tide, the additional areas affected are evenly distributed around the Bay and are barely distinguishable on maps. Furthermore, the difference may likely be attributable to the resolution of the elevation data upon which the USGS work is based. Consultation with USGS and other experts confirmed that the difference is well within the uncertainty of the data and the analyses.

chance of occurring during any given year (an annual probability of 0.01). A one-year flood has a 100 percent chance of occurring once during a year (an annual probability of 1.0). The most significant finding from analysis performed by USGS is that the area within the current 100-yr flood plain is roughly equivalent to the average monthly high tide in 2050, (Knowles 2008). Simply stated, today's extreme flood event is about the same as a mid-century high tide. In other words, the probability of flooding within the current 100-year flood plain will increase from one percent per year now to 100 percent by mid-century. Because flood protection is generally constructed to last 100 years, the most protective approach is to construct shoreline protection for 55 inches of sea level rise under the 100-year scenario.

Vulnerability from Subsidence. In some areas of the Bay, relative sea level rise, rather than global sea level rise, may provide the most accurate measure of water level along the Bay shoreline. Relative sea level rise is the sum of global sea level rise and the change in vertical land motion. Thus, if sea level rises and the shoreline subsides[2], the relative rise in sea level could be greater than the global rise. For many years the South Bay shoreline, including urbanized areas and salt ponds, experienced high rates of subsidence from groundwater depletion, which has now stopped. Where subsidence continues, relative sea level rise could cause more significant shoreline flooding in those areas than it would if the shoreline land mass remained at a constant level, or rose (BCDC 1988). As rates of global sea level continue to increase with climate change, at some point, the rate of vertical land movement will become less significant in determining the impact of sea level rise. However, areas that have subsided are particularly vulnerable to sea level rise and extreme events.

The Suisun Marsh is one area of the Bay where relative sea level rise is significant, due to ongoing subsidence. When managed wetlands (wetlands behind levees) such as the Suisun Marsh are allowed to dry out, the organic matter in the soil oxidizes. Loss of this organic matter may lead to local and regional ground subsidence. The continuing subsidence of managed wetlands can affect levee stability and increase the risk of failure (DWR, 1995; Mount and Twiss, 2005). Levee failure during floods in the Suisun Marsh and the Delta will cause saltwater intrusion into groundwater aquifers, saltwater contamination of agricultural lands, and changes to the salinity of freshwater ecosystems.

---

[2] Subsidence, or sinking of the land surface, is generally caused by: vertical motion along a fault line, applying loads to incompetent soils, oxidation of organic matter in soils, or groundwater withdrawal from the subsurface of the land resulting from compaction.

San Francisco Bay
Conservation and Development Commission

Figure 1.7

South Bay
Shoreline Areas Vulnerable To Sea Level Rise

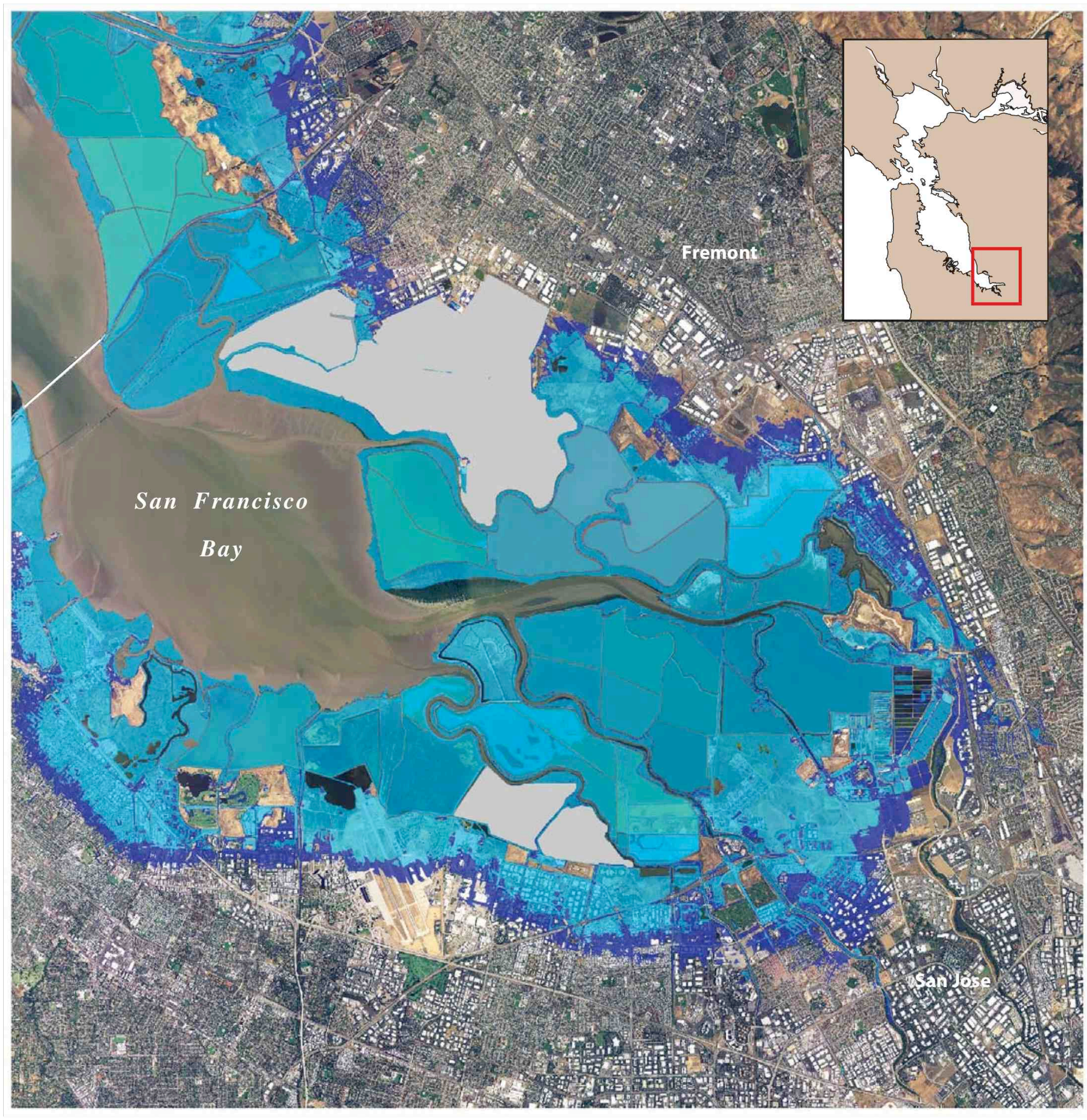
Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise

No data

0 1 2 3 MILES

NORTH



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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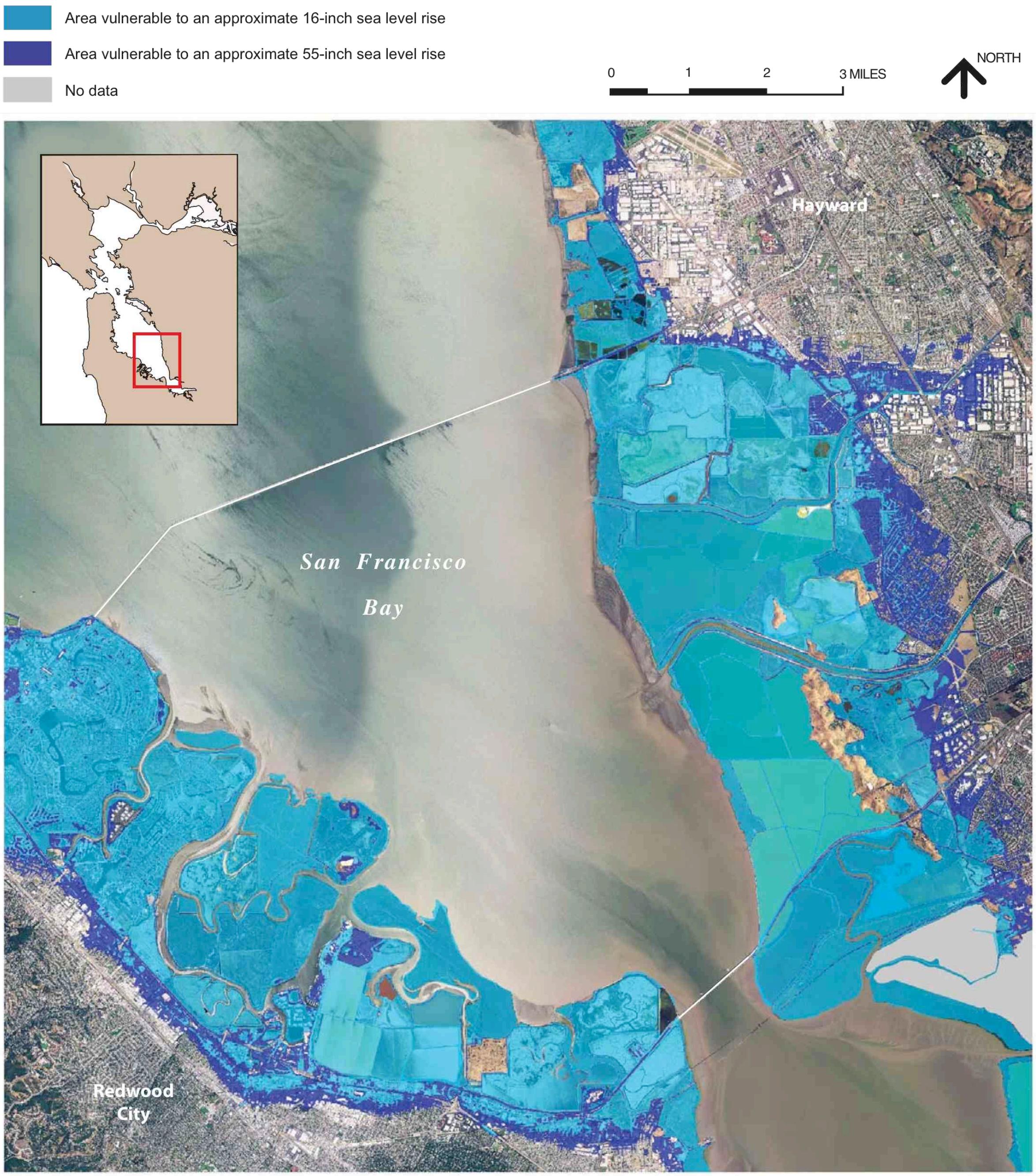
San Francisco Bay
Conservation and Development Commission

Figure 1.8

Central Bay South
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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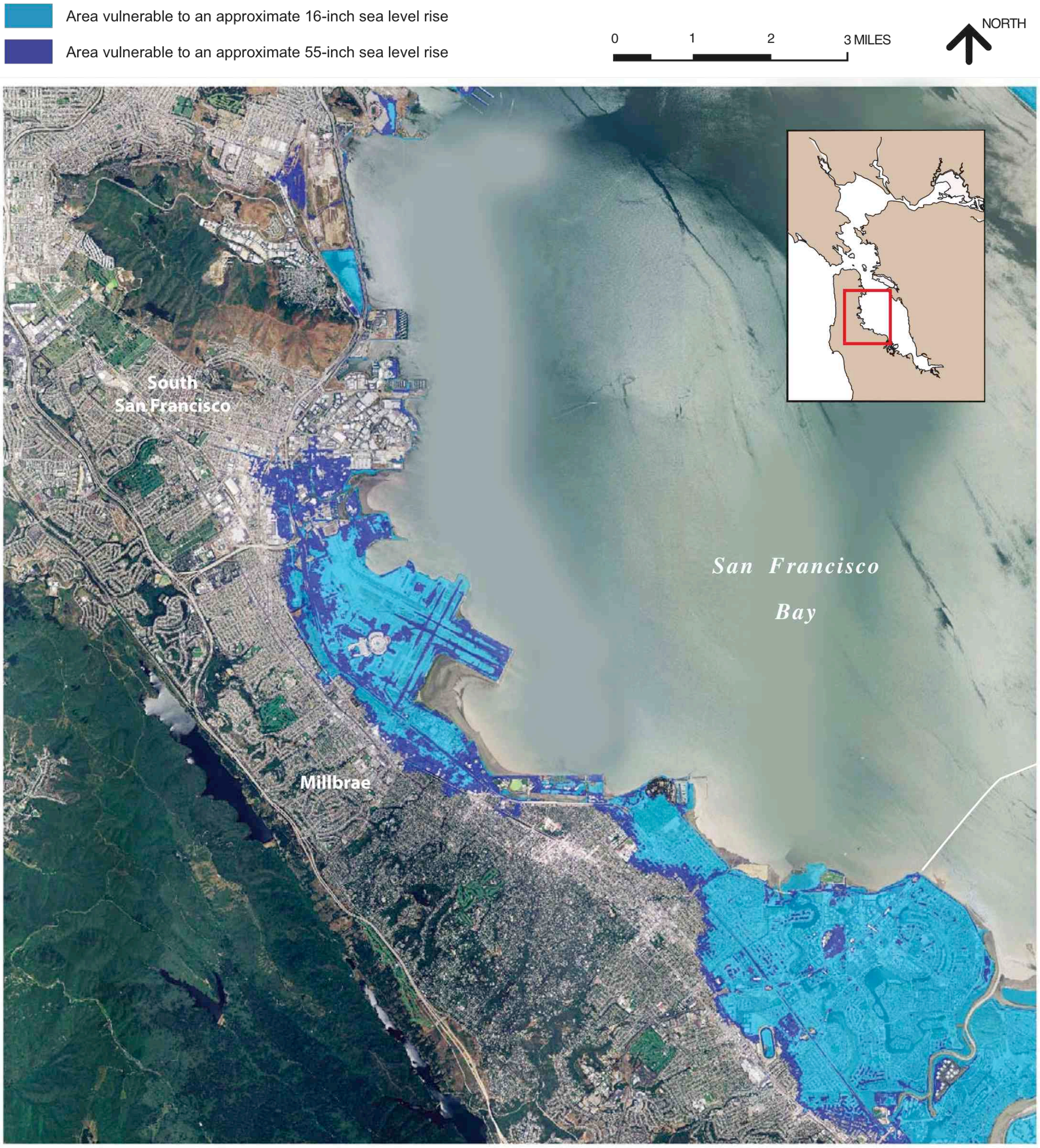
San Francisco Bay
Conservation and Development Commission

Figure 1.9

Central Bay West Shore
Shoreline Areas Vulnerable To Sea Level Rise

Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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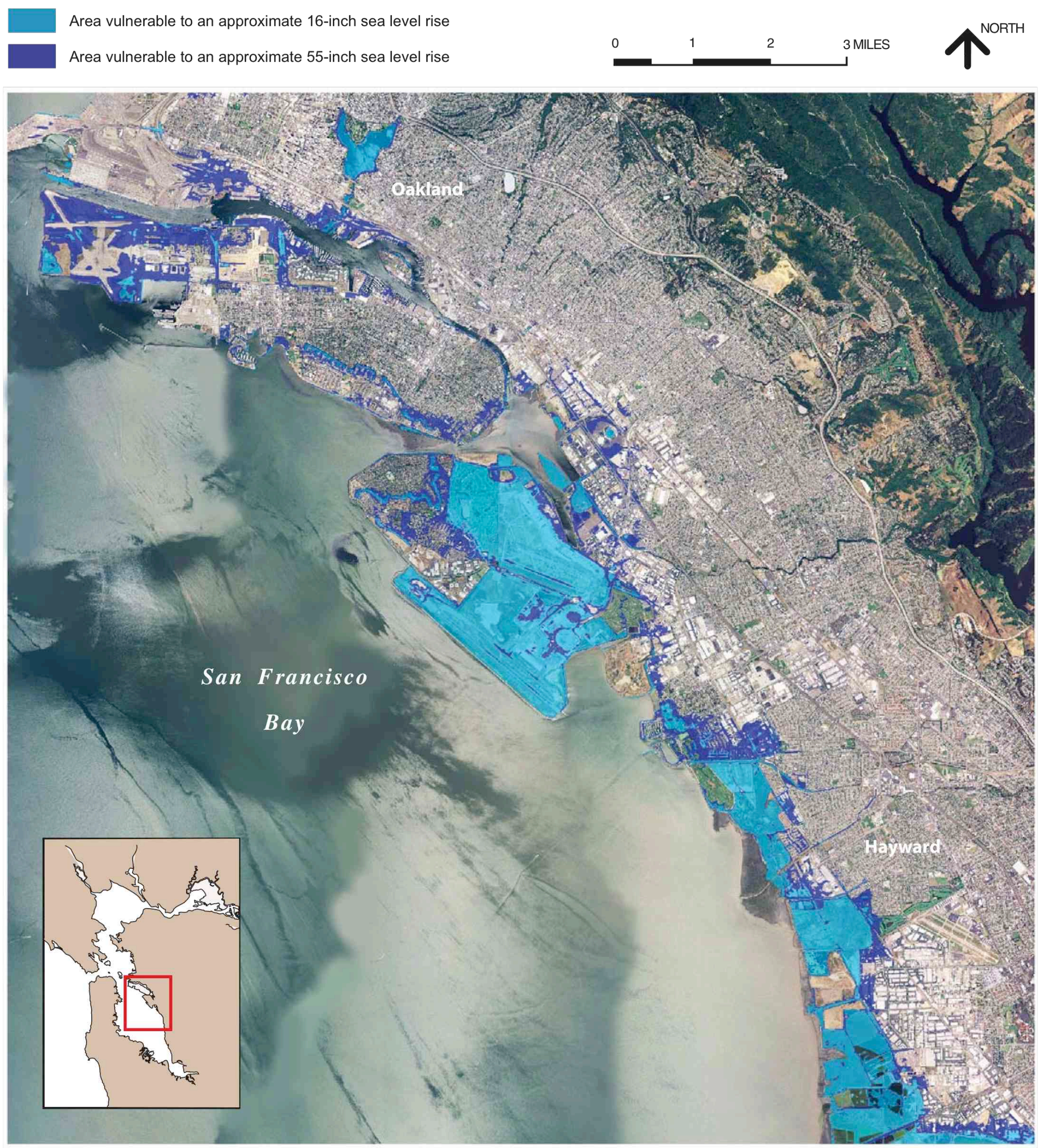
San Francisco Bay
Conservation and Development Commission

Figure 1.10

Central Bay East Shore
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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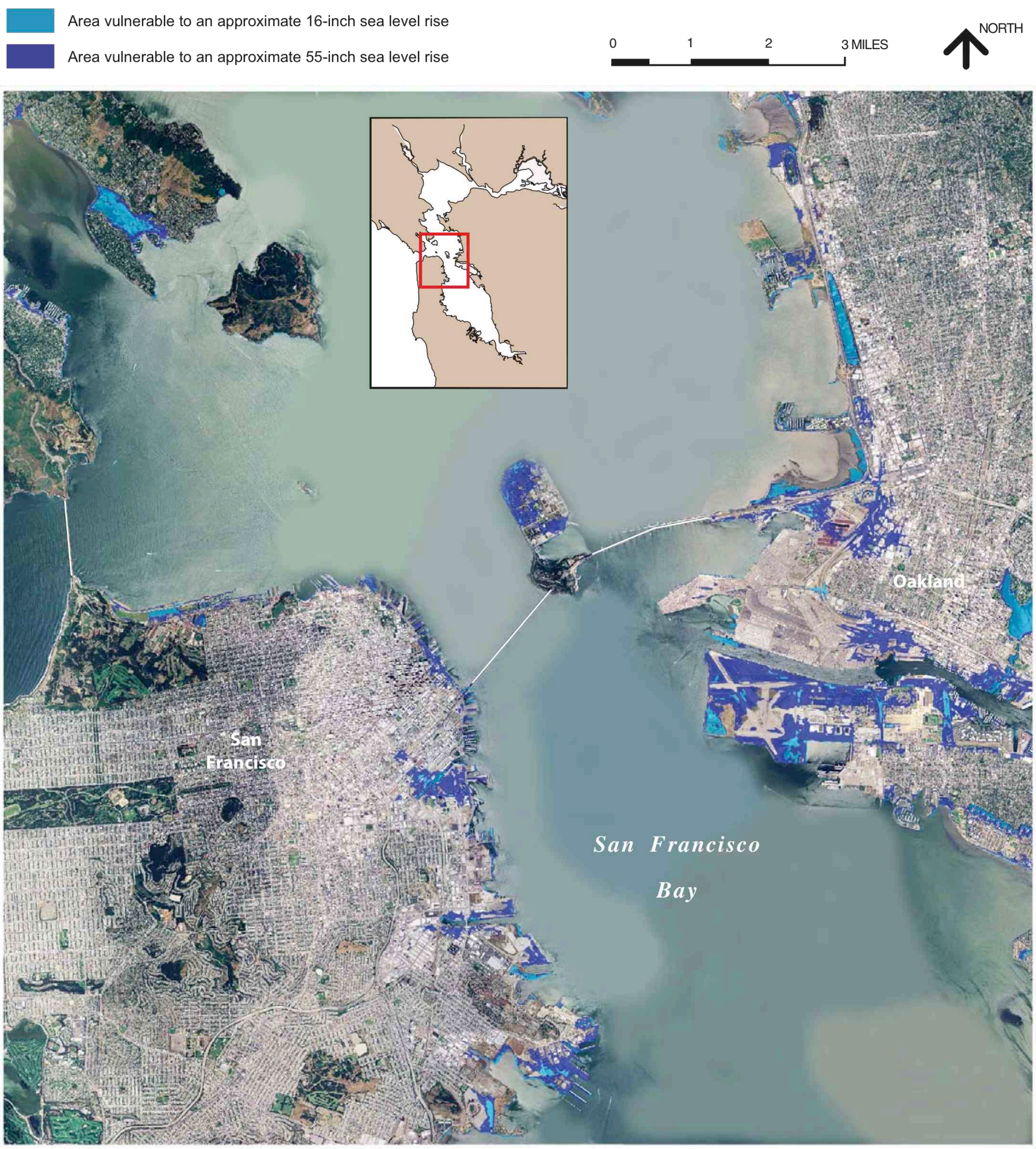
San Francisco Bay
Conservation and Development Commission

Figure 1.11

Central Bay
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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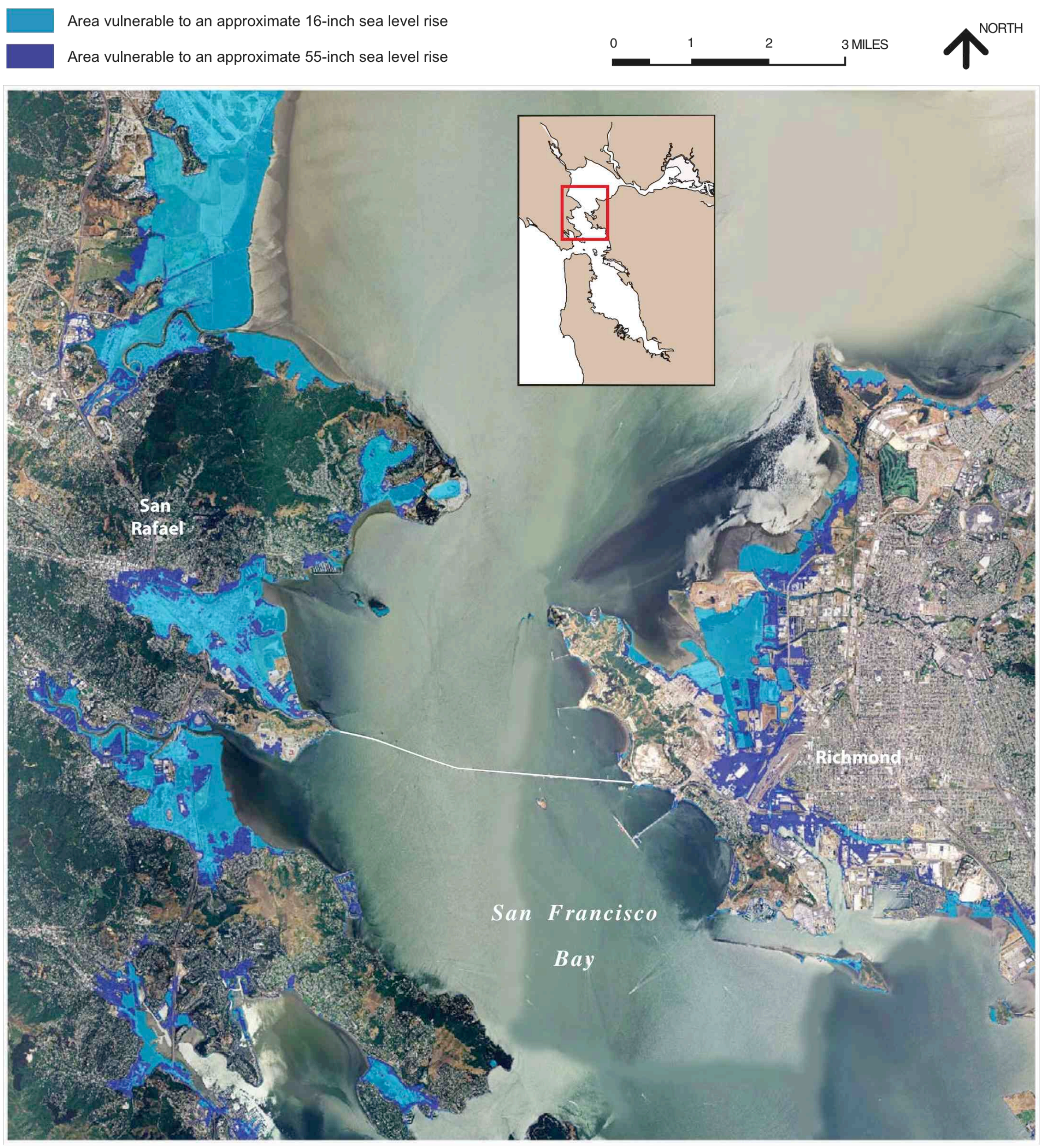
San Francisco Bay Conservation and Development Commission

Figure 1.12

Central Bay North
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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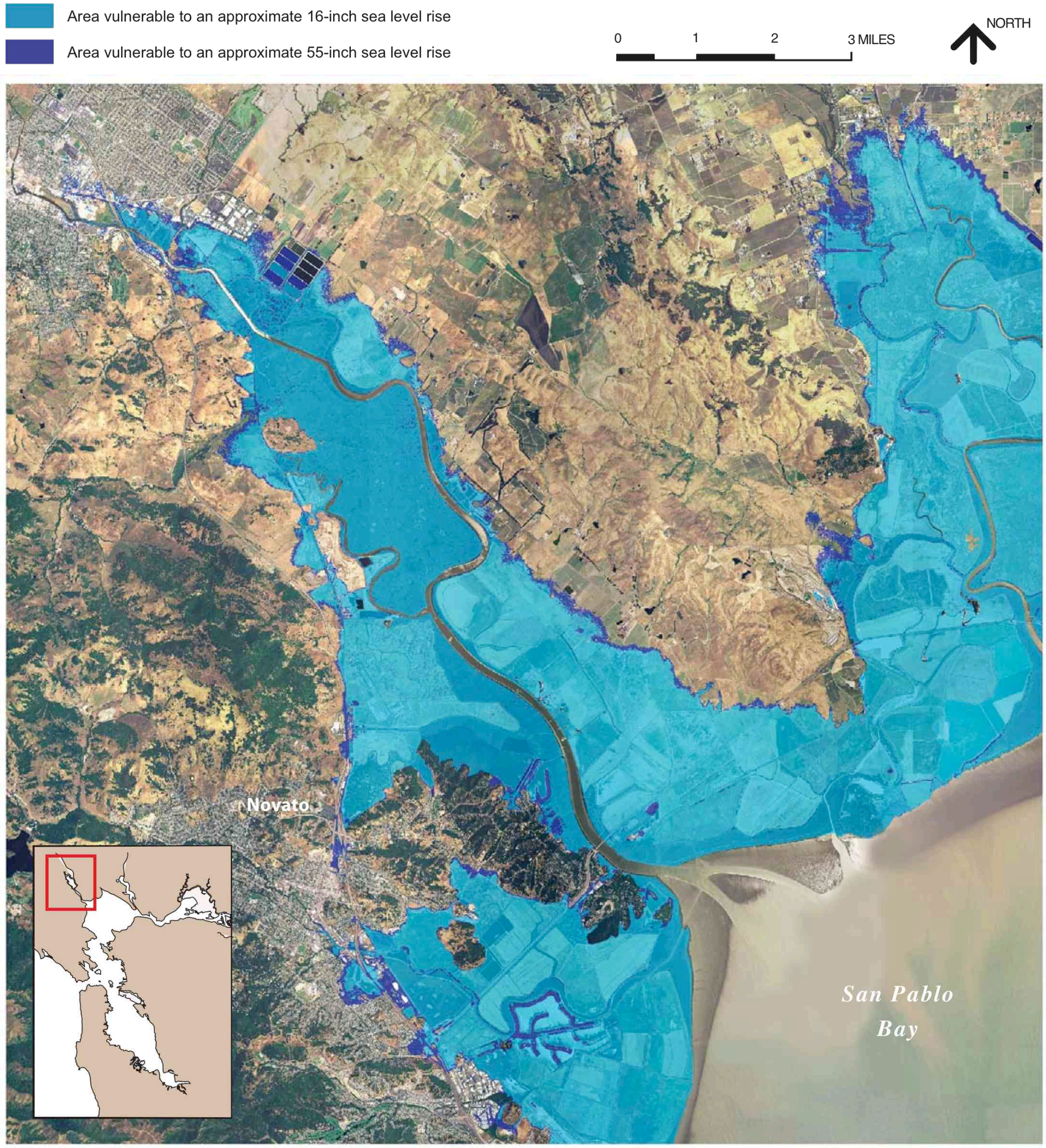
San Francisco Bay
Conservation and Development Commission

Figure 1.13

Petaluma River
Shoreline Areas Vulnerable To Sea Level Rise

Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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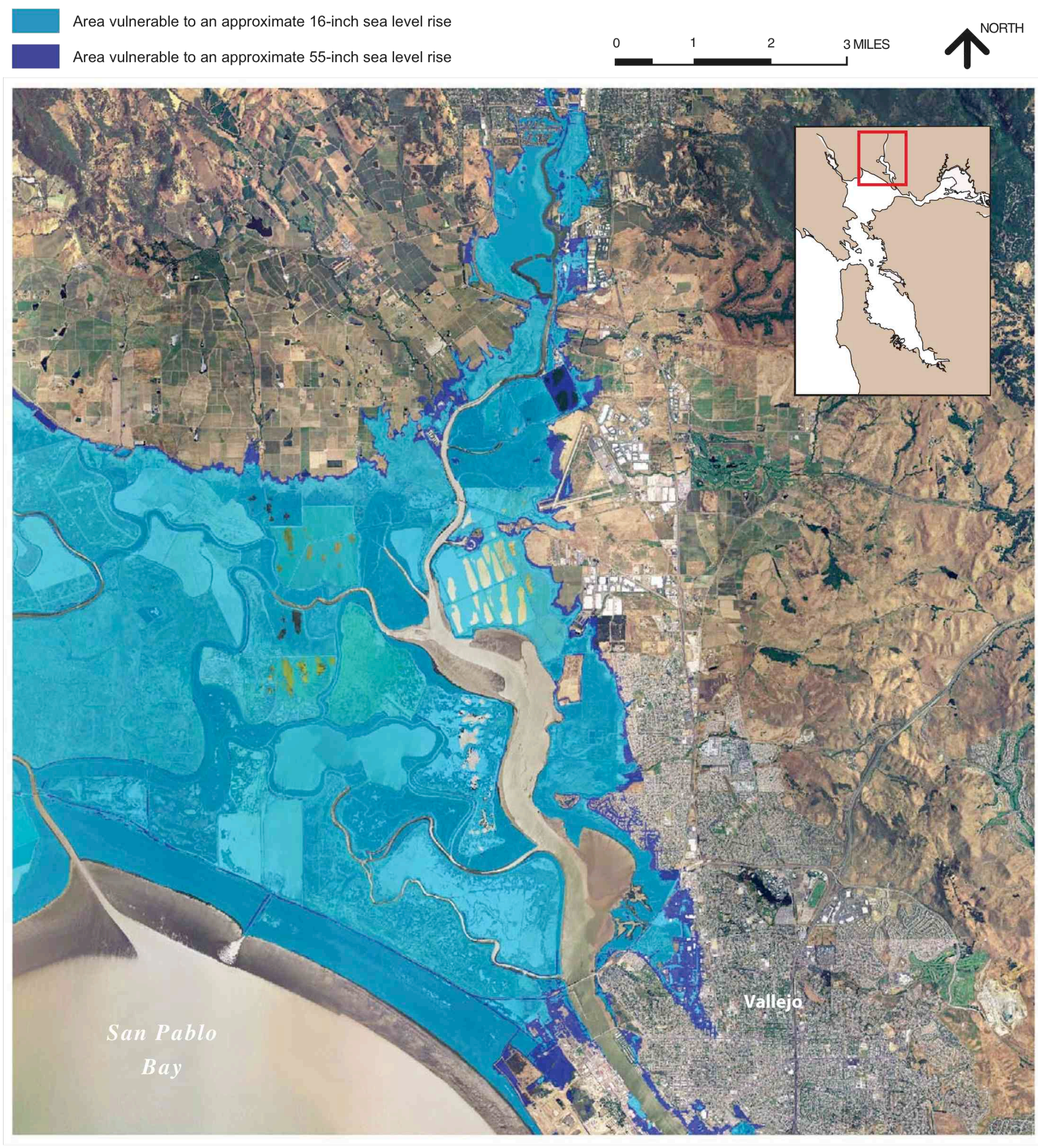
San Francisco Bay Conservation and Development Commission

Figure 1.14

Napa River
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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San Francisco Bay
Conservation and Development Commission

Figure 1.15

San Pablo Bay/Carquinez Strait
Shoreline Areas Vulnerable To Sea Level Rise

Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise

0 1 2 3 MILES

NORTH

NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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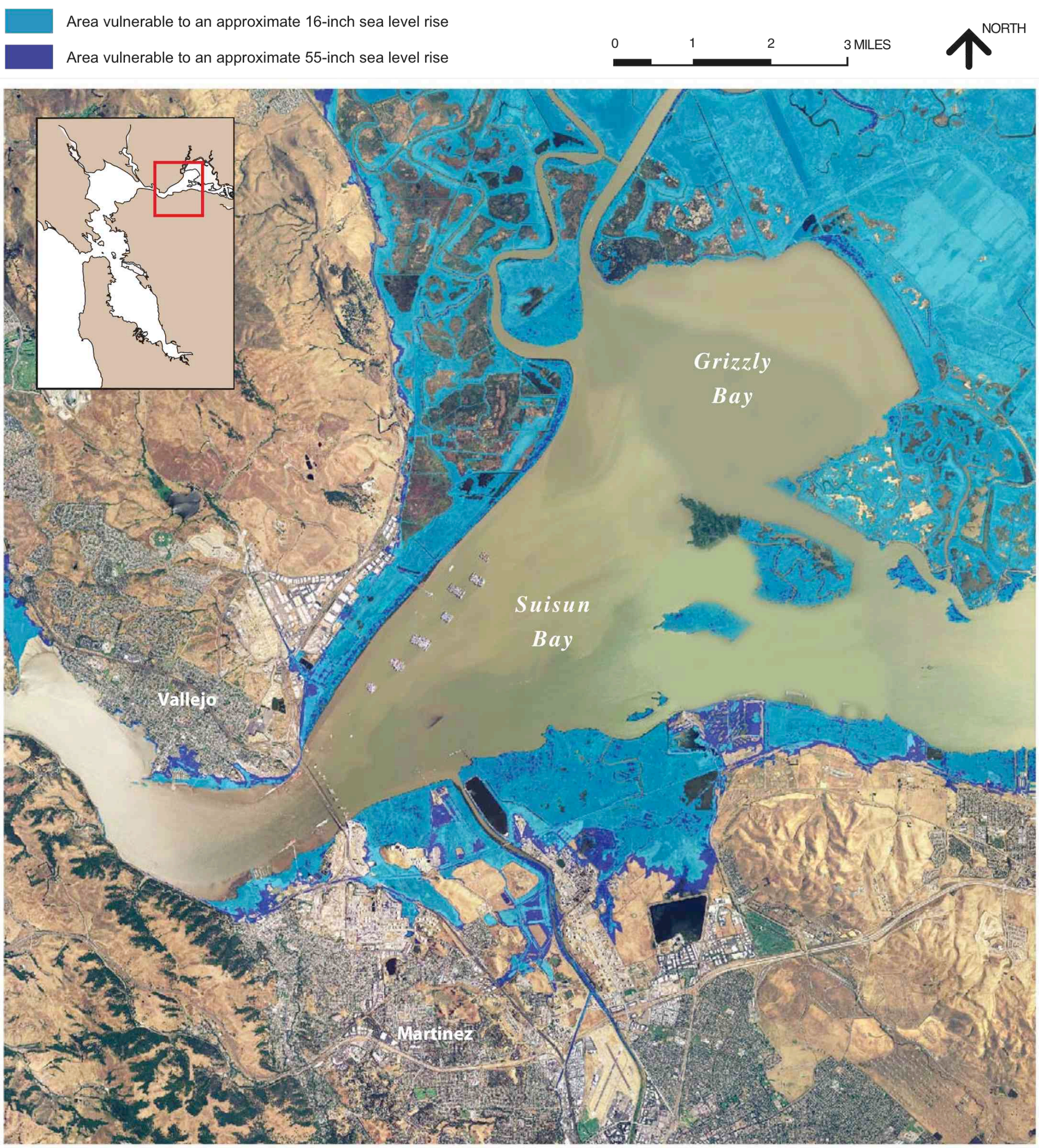
San Francisco Bay
Conservation and Development Commission

Figure 1.16

Grizzly Bay
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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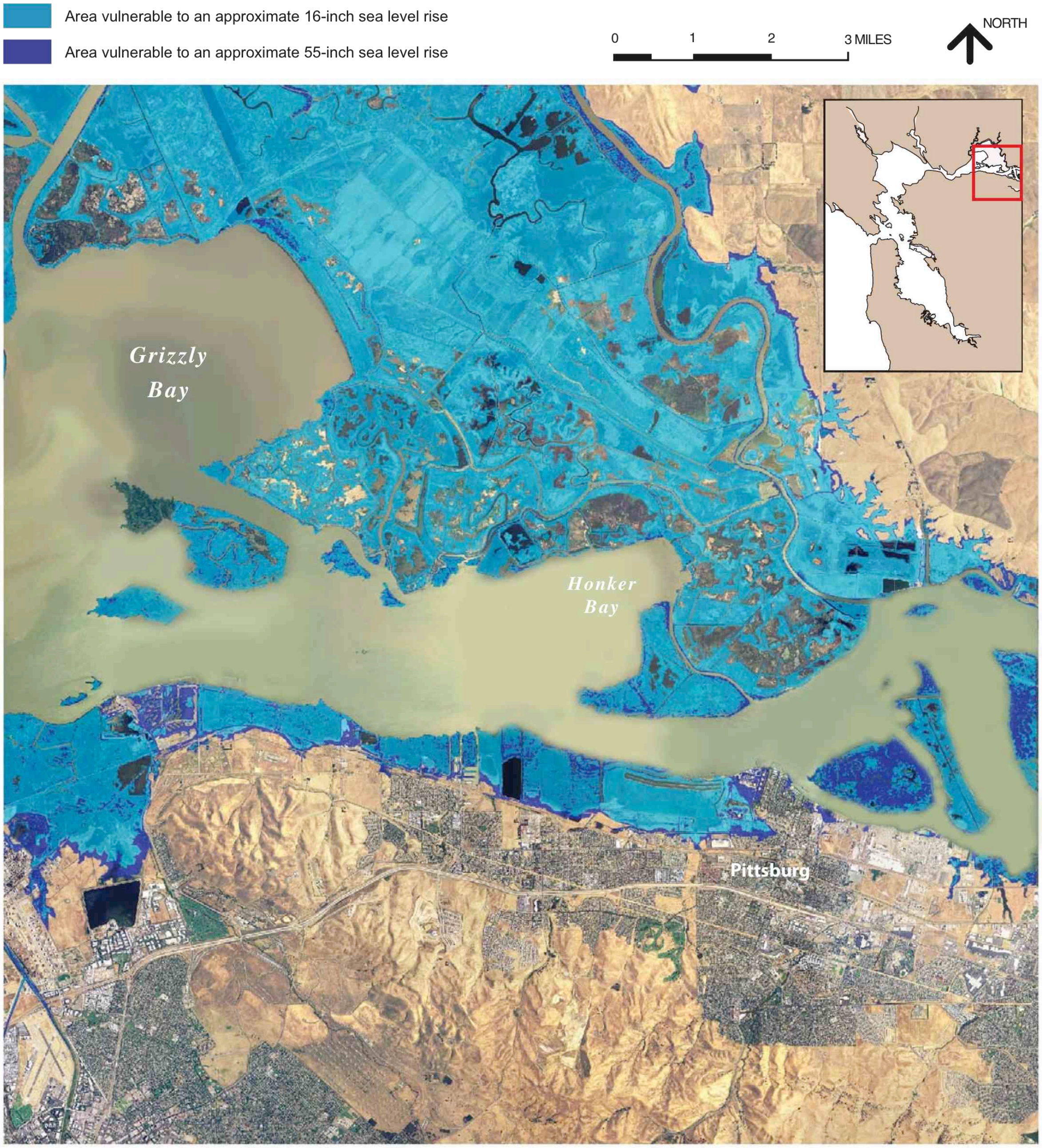
San Francisco Bay
Conservation and Development Commission

Figure 1.17

Honker Bay
Shoreline Areas Vulnerable To Sea Level Rise

Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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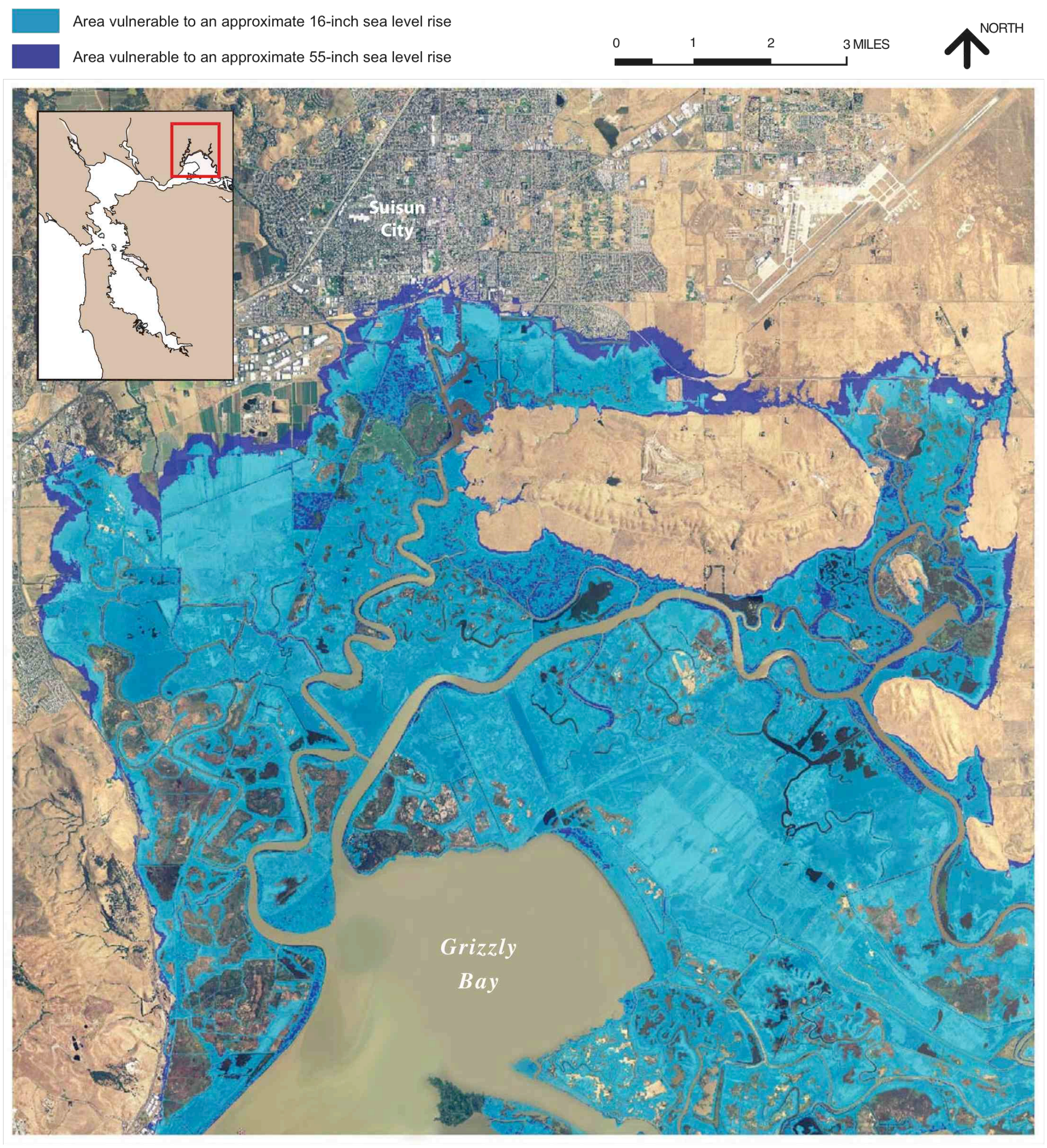
San Francisco Bay
Conservation and Development Commission

Figure 1.18

Suisun Marsh
Shoreline Areas Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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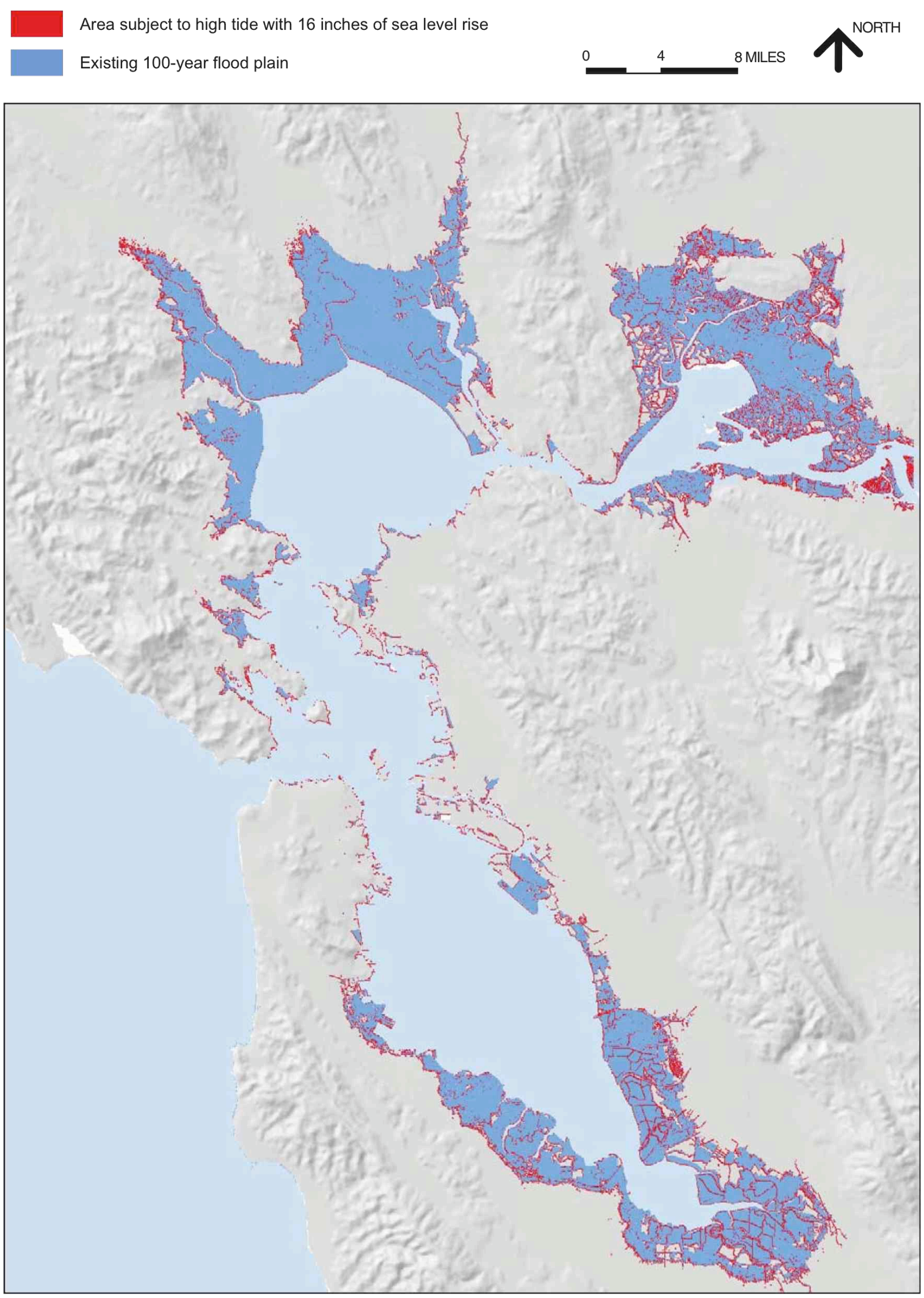
Figure 1.19

Current 100-Year Flood Plain and Area at Increased Risk from Future Sea Level Rise



SOURCE: Inundation data Knowles, 2008. Data does not account for existing levees or other shoreline protection.

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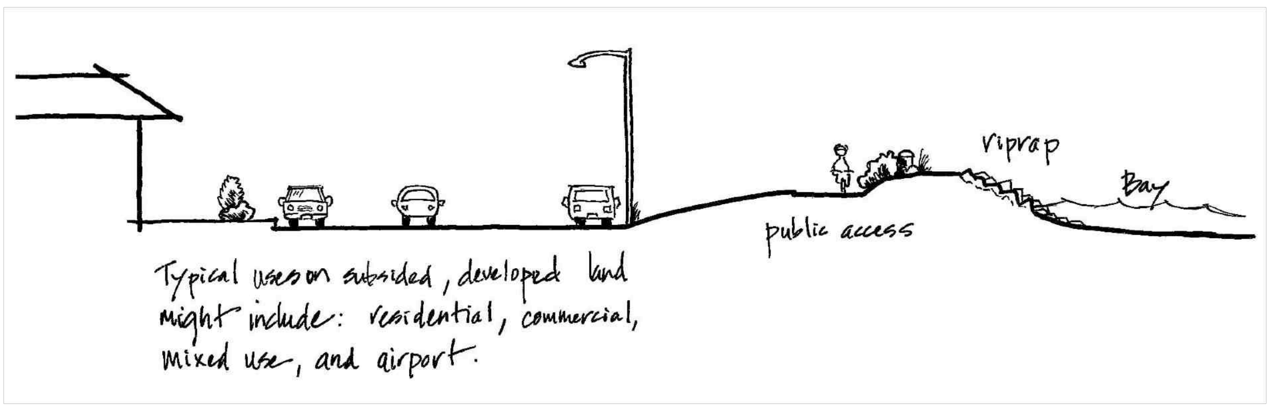
Shoreline Protection

San Francisco Bay and the shoreline support some of the densest urban development in the United States as well as ample open space and some of the most extensive wetland habitats (Figure 1.6). Shoreline development, public safety, and the Bay ecosystem are at risk from current flooding and increased future flooding and storm activity. Public infrastructure and shoreline development that are critical to the region's health, safety and welfare will require protection. Wetlands must be sustained to continue providing important habitat and healthy functioning of the Bay ecosystem. A variety of shoreline features and development exist around the Bay, some of which are more vulnerable than others and all present unique challenges for protection and adaptation to sea level rise[3]. Discovering ways to protect shoreline development and wetlands is one of the major challenges in adapting to future sea level rise.

Figure 1.20 Typical Section: Subsided Land with Structural Shoreline Protection

Source: BCDC



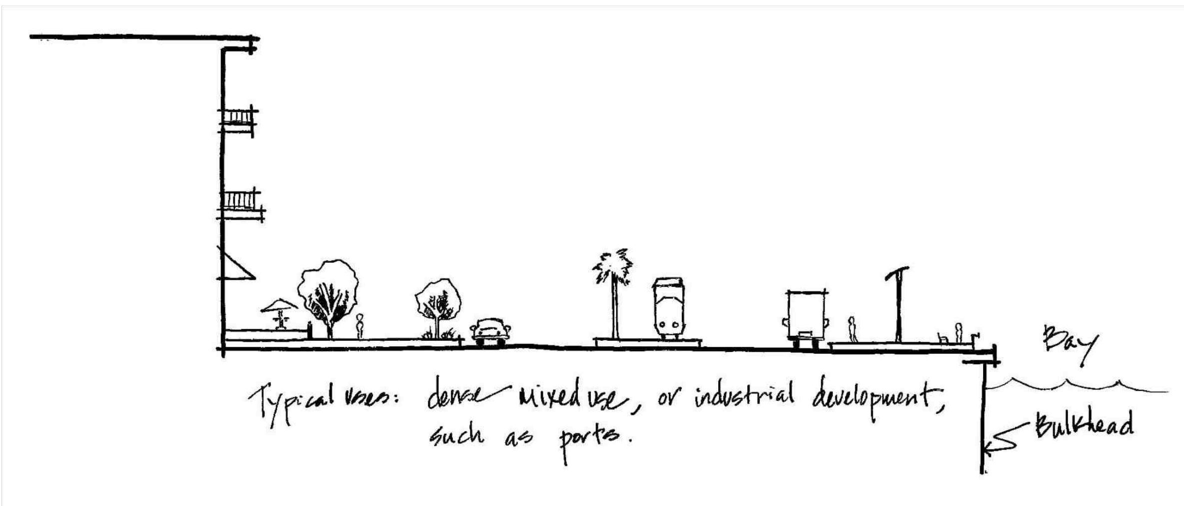
Sea level rise and flooding on the Bay shoreline will lead to a greater risk of erosion, causing local governments and landowners to evaluate protection techniques and strategies. Currently, static structures or structural protection, such as seawalls, riprap revetments and levees, are the most common form of protection against flooding and erosion along the shoreline (Figures 1.20-1.22). Although expensive, these structures are attractive options because the engineering

3 A series of figures showing typical shoreline conditions are included to further an understanding of the variety of shoreline conditions discussed here and in future chapters.

standards for their design and implementation are fully developed and widely used (BCDC 1988a, Smits et. al. 2006). Static structures on the edge of a dynamic Bay shoreline can result in erosion of adjacent tidal wetlands and eventually the flood protection itself (Williams 2001, Lowe and Williams 2008, Schoellhammer et. al. 2005, Smits et. al. 2006, Heberger et. al. 2008).

Figure 1.21 Typical Section: Urban Shoreline with Bulkhead

Source: BCDC

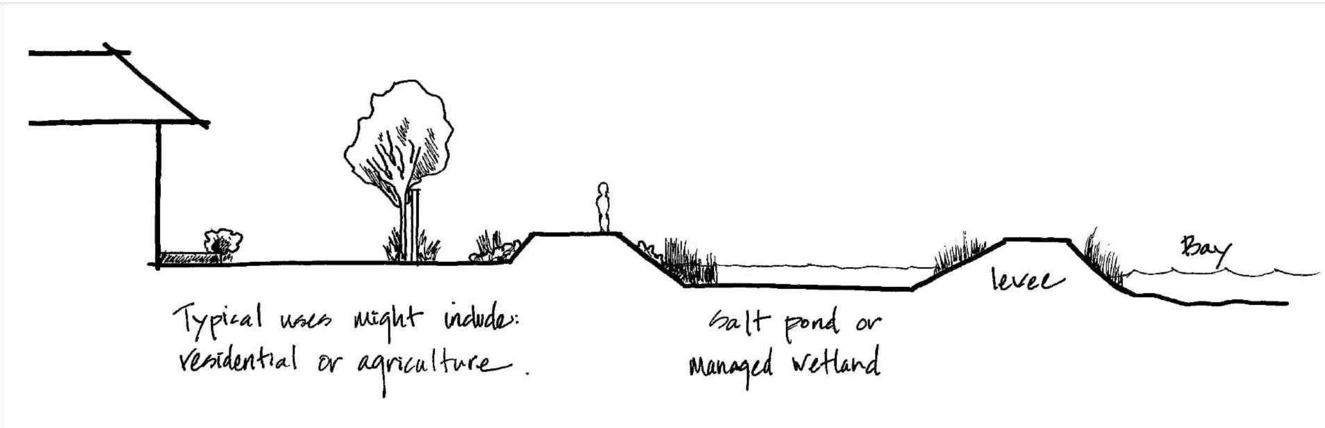


Construction and maintenance of shoreline protection typically requires fill in the Bay (BCDC 1988a). From 1978 to 1987, BCDC authorized nearly 300,000 cubic yards of fill for shoreline protection, most of which was used to construct riprap revetments (BCDC 1988a). Many of these revetments degraded tidal flats that provide important habitat to birds and dissipate wave energy. Thus, residential communities and infrastructure on the shoreline, as well as the Bay ecosystem, may be significantly impacted by the cumulative effect of additional engineered structures along the Bay shoreline to address sea level rise.

Both the construction and maintenance cost of protection structures increases over time, particularly as sea level rises and the damaging effect of storms increases. Since 1990, the construction cost of a waterside levee rose to approximately $1,500 per linear foot, a 320 percent increase, and seawalls are even more expensive at approximately $5,300 per linear foot (Heberger et. al. 2008). Maintenance costs range from 1-15 percent of the construction cost per year over the life of the project, which does not include the cost of damages to public safety, infrastructure, or the ecosystem (Heberger et. al. 2008).

Figure 1.22 Typical Section: Wetlands and Levees

Source: BCDC



The Pacific Institute reports that statewide the cost of protecting against a 55-inch rise in sea level using static structures would be $14 billion. This cost estimate assumes that, throughout the Bay, levees are sufficient to provide shoreline protection. However, the existing shoreline protection is a mix of levees, riprap and bulkheads or seawalls. Evaluating the full cost of protection measures on the Bay shoreline requires a full assessment of existing structures, both in terms of the level of flood protection and the resistance to erosion under sea level rise scenarios. In many cases, the wave energy will be sufficient that local governments may desire the additional protection of a seawall, which is far more expensive. Furthermore, Bay levees are constructed, in many cases, by loosely compacted Bay mud and are insufficient to support the additional weight of material required for retrofitting (URS 2005, PWA 2005). This deficiency is offset, to a degree, because the cost estimate is based on areas vulnerable to sea level rise and flooding irrespective of whether current protection exists—a more risk-averse approach. Considering that there are multiple types of shoreline protection other than levees, and that where existing levees cannot be raised, they may require replacement with an alternative method of protection, the cost estimate for the Bay is probably a low cost estimate.

Providing structural shoreline protection may actually increase vulnerability by encouraging development in flood-prone areas directly behind the structure and giving those who live behind the structure a false sense of security (Heberger et. al. 2008, Smits et. al. 2006, United Nations 2004). In areas of the Netherlands, as progressively larger protection structures were built, development behind the structures intensified and populations in those areas increased. The protection structures completely eliminated water circulation in several estuaries, which were ultimately abandoned as functioning ecosystems (Smits et. al. 2006). Large areas of the Mississippi Delta are being considered for restoration, in part, to restore previous wave attenuation benefits and help avoid repetition of the devastating impacts caused by Hurricane Katrina, a tragic example of relying too heavily on shoreline protection structures (Day et. al. 2007). Loss of this ecosystem benefit is just one of the reasons for ambitious tidal wetland restoration efforts in the Bay-Delta estuary (Save the Bay 2007). While sedimentation and tidal wetlands alone may not completely protect against flooding and erosion (Jongejan 2008), early adaptation of existing development, prevention of new development in flood prone areas, and the flood protection benefit of tidal wetlands can help reduce the cost of adaptation.

The *San Francisco Bay Plan* (Bay Plan) requires a design review process for engineering projects, such as major shoreline protection works. The Bay Plan also includes policies to guide the Commission decisions regarding compensatory mitigation for unavoidable adverse impacts resulting from projects in the Bay. Few remaining locations for mitigation exist and sea level rise may result in additional habitat loss. Approving structural shoreline protection on a project-by-project basis may create additional, cumulative adverse impacts to Bay habitat. Analysis of these cumulative impacts is needed and potential planning approaches that will minimize them is needed. Both the USGS and the USACE are currently investigating regional and local effects of shoreline inundation and flooding, respectively, in the South Bay. Additional analysis can provide local governments and landowners with adequate information for designing erosion control and shoreline protection (Knowles 2008, USACE 2008).

Summary and Conclusions

The planet is getting warmer and there is broad scientific consensus that human release of GHGs is driving this change. Greenhouse gases that naturally reside in the earth's atmosphere, absorb heat emitted from the earth's surface and radiate heat back to the surface—a natural process called the "greenhouse effect." The planet is now warming at an accelerated rate due largely to the rapid release greenhouse gases in the atmosphere since industrialization. Temperatures in California are projected to rise between 1.8°F and 5.4°F (1°C and 3°C) by mid century and between 3.6°F and 9°F (2°C and 5°C) by the end of the century. As temperatures warm, the oceans warm, land-based ice and ice sheets melt, causing sea level to rise.

A range of sea level rise scenarios have been estimated, but they may not adequately reflect future contributions from ice-sheet melt. The estimates for this analysis are based on higher GHG emissions scenarios. Choosing a higher scenario is a more risk-averse approach to protecting public safety. Two sea level rise scenarios were selected for analysis: a 16-inch (40 cm) sea level rise by mid-century and a 55-inch rise in sea level by the end of the century. These scenarios are generally consistent with other state SLR estimates.

Extreme storm events will cause most shoreline damage from flooding. Changes in climate may increase storm activity, which in combination with higher sea level, will result in flooding. The data used for this analysis reflects storm activity, but does not include wave activity. With the 16-inch scenario, 180,000 acres (281 square miles) of shoreline are vulnerable to flooding by mid-century and 213,000 acres (332 square miles) are vulnerable to a 55-inch sea level rise at the end of the century.

Structural shoreline protection can hold flood waters back from the shoreline. It requires long-term maintenance and can have unintended adverse impacts and, for these reasons, should be seen as a short-term solution to flooding from sea level rise. (BCDC 1988a, BCDC 1988b, Smits et. al. 2006). Resilient shoreline protection, incorporating both engineering and ecosystem elements, should be used to present a balanced solution over the long term (Lowe and Williams 2008). Cumulative impacts of structural shoreline protection can have far reaching adverse impacts to the Bay ecosystem. Planning for sea level rise at a regional level can reduce those impacts and address difficult issues, such as the desire to provide shoreline protection on undeveloped shoreline. Where shoreline protection is necessary to protect development, it should be constructed to provide protection for a 100-year flood with the addition of 16-inches of sea level rise, at a minimum.

CHAPTER 2
The Shoreline Environment

Vibrant cities, towns, communities, international airports, critical businesses, research facilities, freeways, railroads, parks, trails and important habitat areas stretch along the shoreline of San Francisco Bay. These shoreline land uses are essential to the region's economy, provide needed housing and jobs for the region's residents, provide habitat for many ecological communities and allow the public to enjoy the Bay. In short, continued, productive use of the shoreline is the cornerstone of the region's prosperity and fosters a strong bond between the region's residents and the Bay.

The nine county San Francisco Bay Area is home to approximately seven million people, making it the nation's fifth most populous urban center. All nine counties—San Francisco, San Mateo, Santa Clara, Alameda, Contra Costa, Solano, Napa, Sonoma, and Marin—front on the Bay. There are 101 cities within the region and 46 cities situated along the shoreline making the San Francisco Bay one of the world's most urbanized estuaries. The Bay Area's three largest cities are, San Jose (pop: 894, 943), San Francisco (pop: 776, 773), and Oakland (399, 484) (U.S. Census Bureau, 2000).

The San Francisco Bay Area is one of the most economically productive regions in the nation (Bay Area Council Economic Institute, 2008). The highly skilled workforce is employed in a variety of fields, including health care, technology, information services, finance, education, life sciences, manufacturing and retail. The natural harbor and its proximity to Pacific trading partners allow the region to export more products than most states (Bay Area Council Economic Institute, 2008). The Bay Area is also home to some of the world's leading universities and research institutions making it a key global center for innovation.

An estimated 270,000 people in the Bay Area are at risk of flooding from a 55-inch rise in sea level—a 98 percent increase over the region's current vulnerability to flooding (Heberger 2008). Shoreline development at risk (buildings and their contents) is estimated at $62 billion—nearly double the estimated cost of sea level rise flood risk along California's Pacific Coast (Heberger et. al. 2008). Where lives and property are not directly vulnerable, the secondary and cumulative impacts of sea level rise will affect public health, economic security and quality of life.

Shoreline planners and managers already face challenging issues, such as managing competing land uses, ensuring that shoreline areas are available for water-dependent uses, upgrading aged infrastructure, reducing traffic congestion, protecting habitat and water quality, maintaining flood protection, and providing public shoreline access. In this chapter, shoreline vulnerability is assessed to understand planning and management challenges that may be exacerbated with climate change and identify new challenges that may arise.

Residential Land Use

Land use patterns vary significantly within the region, San Francisco County is the most urbanized with 82 percent of its land developed while rural Napa County, a highly productive agricultural area, has less than four percent of its land developed. Approximately 16 percent, about 700,000 acres (1,093 square miles), of the region's 4.4 million acres (6,875 square miles) are developed. Over half of this urbanized area is residential and approximately 40 percent contains employment centers, major infrastructure and schools (ABAG, 2008). In addition to urban areas, the region has extensive, productive agricultural lands and abundant open space and parks. Within the area vulnerable to a 55-inch rise in sea level, approximately 51 percent is residential, 32 percent is commercial, and 14 percent is industrial.

Much of the shoreline is former Bay that was filled to create land for housing. Construction of levees along the Bay margin and channeling of creeks and rivers opened up large tracts of land for residential development, most of which is in the current 100-year floodplain. In accordance with the National Flood Insurance Program standards, local governments established elevation requirements for levees, homes, and local roads in floodplains to lessen potential flood risks. However, these standards are based on past flooding events rather than future sea level rise and storm events. Residential development located on subsided land and near the mouth of Bay tributaries—especially at the head of tide where high tide meets tributary outflow—are particularly vulnerable to flooding. One such community is the town of Alviso, in northern San Jose, whichis subject to both sources of vulnerability—it has significantly subsided and sits in close proximity to Alviso Slough. Storm-related flooding already affects some communities in low-lying and riparian areas, such as Corte Madera and Petaluma.

Difficult choices at the local and regional level are required to determine how to protect housing from future flooding. Approximately 66,000 residential acres (103 square miles) are vulnerable to a 16-inch sea level rise. Most of this acreage is developed with low-density housing (less than 5 residents per acre). However, 560 acres (0.8 square miles) have over 30 residents per acre and over 5,600 acres (8 square miles) have between 5 and 30 residents per acre. Over 82,000 residential acres (128 square miles) are vulnerable to a 55-inch sea level rise. While most of this area is used for low-density housing, over 1,000 acres (1.5 square miles) contain over 30 residents per acre and over 9,800 acres (15 square miles) contain between 5 and 30 residents per acre (Table 2.1). Through the JPC, the Commission is a partner in an incentive-based program to focus development near transit and, thereby, reduce driving and GHG emissions. This program, among other important goals, should consider alternatives to siting residences in areas that are vulnerable to flooding (Box 2.1).

Table 2.1 Residential Acreage Vulnerable to Flooding

Residential Land Use	Approximate Acreage Vulnerable to Flooding	
	16-inch sea level rise	55-inch sea level rise
Low-density	59,900	72,100
Medium-density	5,600	9,800
Higher-density	560	1,000
Total	66,000	82,000

Low-Income Residences. One definition of a resilient community is a community that "takes intentional action to enhance the personal and collective capacity of its citizens and institutions to respond to, and influence the course of social and economic change" (CCE 2000). A critical characteristic that enables communities to respond to and influence social and economic change is their current economic security, because it adds to their overall feeling of safety and security (Coburn 2008). Other attributes of resilient communities, such as active participation in democracy, willingness to draw on resources within the community, or confidence (Coburn 2008) may be compromised by a lack of economic security. For example, a low-income community may have a willingness to draw on resources within the community, but several of the essential resources on which to draw are missing: money being the obvious resource; or time spent working and commuting that might otherwise be available as a resource.

A number of low-income communities on the Bay shoreline are vulnerable to sea level rise. A disproportionate number of low-income residents are vulnerable to a 55-inch rise in sea level in five Bay Area counties: Contra Costa, Solano, Sonoma, Marin, and Napa (Heberger 2008)[4].

[4] This information comes from a statewide study of coastal and Bay shoreline impacts. Marin and Sonoma Coutnies may or may not have greater proportions of low-income residents on the coast or Bay shoreline. Furthermore, because the study applies statewide, a lower percentage was used in the calculation of low-income that may exclude some Bay Area residents (see "5" below).

Box 2.1 The FOCUS Program

FOCUS is a partnership among ABAG, BAAQMD, BCDC, and MTC that encourages future development and growth in areas near existing or planned transit and within existing communities. It is a strategy to work with local and regional entities in the nine-county San Francisco Bay Area by identifying priority development areas (PDAs) that qualify local governments for financial incentives. Priority conservation areas (PCAs) are identified to preserve regionally significant resources, such as agriculture, natural or scenic resources and recreational areas.

PDAs are locally identified, infill development opportunities located within existing communities. They are generally areas of at least 100 acres (0.1 square miles) where there is local commitment to creating more housing in a pedestrian friendly environment that is served by one of the regional transit agencies. The approximately 150 PDAs comprise approximately 106,000 acres (165 square miles) of urban and suburban land. While this constitutes a small percentage of the region's total land area, the proposed areas could accommodate over half of the region's projected housing growth to the year 2035 at relatively modest densities (ABAG website, 2009). Importantly, the increased density around transit can be an effective strategy to reduce greenhouse gas emissions.

Forty PDAs, comprising over 60,000 acres (93 square miles), have a portion of area that is vulnerable to sea level rise. Approximately 2,000 acres (3 square miles) or three percent of the 60,000 acres are vulnerable to a 16-inch sea level rise. Ten percent, or 6,000 acres (9.3 square miles), are vulnerable to a 55-inch sea level rise. It is important to realize that this analysis was conducted with data that identifies the entire extent of the PDA's. It does not necessarily imply that actual development would occur within vulnerable areas. Future efforts should focus on determining the likelihood of secondary impacts upon the identified PDA's, such as impacts to surrounding transportation infrastructure. Appropriate adaptation strategies should be developed for any vulnerable site (Figures 2.1- 2.2).

A low-income community is an area where 30 percent or more of the households earn less than 200 percent of the national poverty threshold.[5] Low-income communities are less likely to have sufficient resources to rebuild housing after a flood or to relocate. The canal district in San Rafael (Figure 2.3) is an example of a predominantly low-income community that is highly vulnerable to flooding.

Low-income communities are likely to be less resilient to the indirect, cumulative impacts of climate change and adaptation efforts. For example, a 16-inch sea level rise will only reach the margins of low-income neighborhoods in Redwood City, East Menlo Park and East Palo Alto (Figure 2.4). However, critical transportation infrastructure that traverse these areas—Highway 101 and the entrances to the Dumbarton Bridge, and Caltrain railroad—will likely be significantly affected by sea level rise. Retrofitting this essential transportation infrastructure could have direct impacts on these neighborhoods. For instance, construction activity on transportation infrastructure can change or disrupt access to public transportation, local shopping, jobs, or medical centers. Easy access to such facilities is something that an automobile-owner or an individual with more flexibility in their work schedule takes for granted. On a regional level, the impacts from disruption of services would be offset by the benefits from retrofitting important highways and rail corridors. Low-income households may have fewer resources or alternatives available to withstand interim impacts.

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5 These thresholds are maintained by the U.S. Census Bureau and are scaled based on size and age of a household. Two hundred percent of the national poverty threshold is the standard equation used by other Bay Area agencies to represent low-income based on the standard of living requirements in the Bay Area.

San Francisco Bay
Conservation and Development Commission

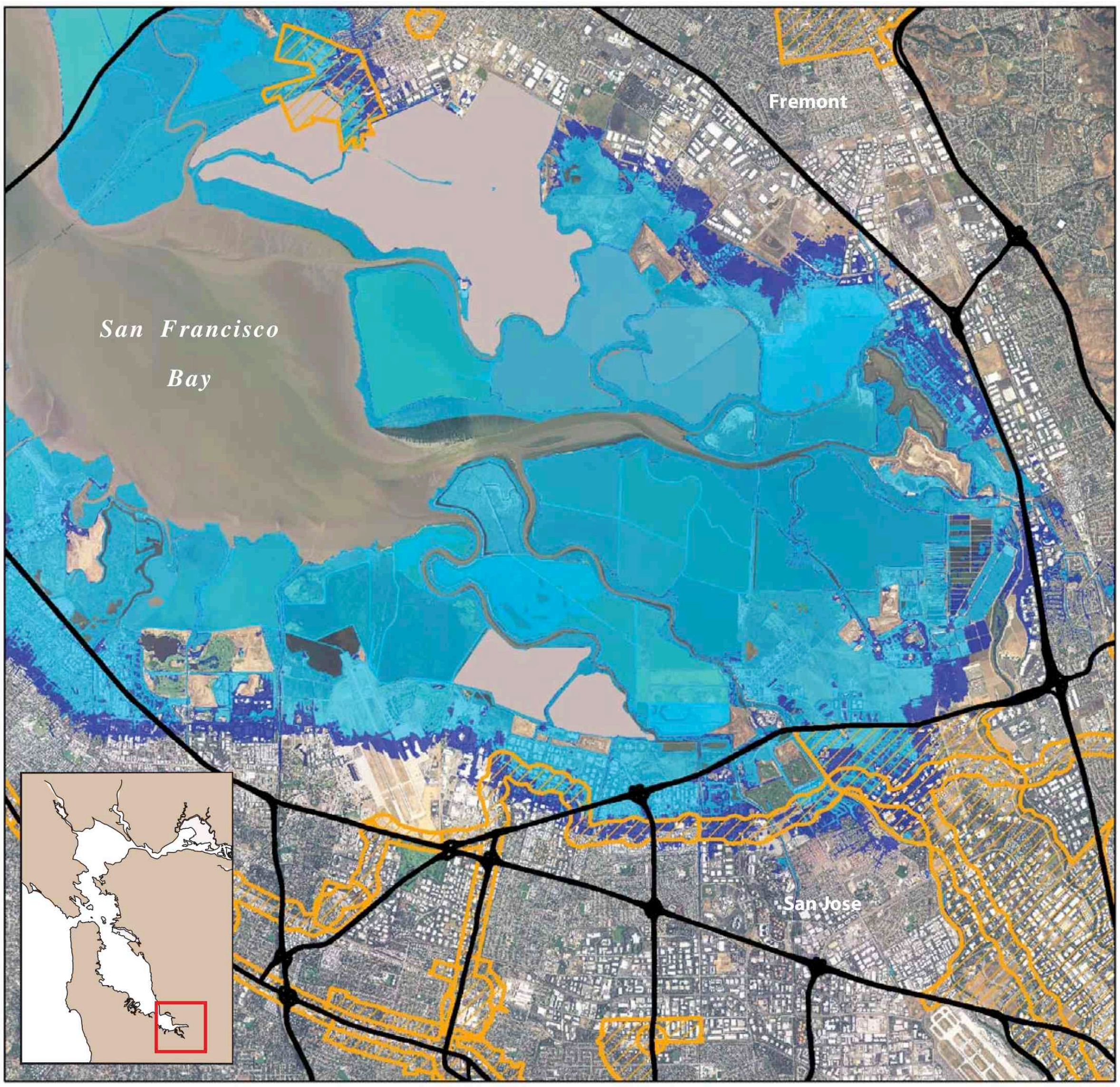
Figure 2.1

South Bay
Priority Development Areas
Vulnerable to Sea Level Rise

- Area vulnerable to an approximate 16-inch sea level rise
- Area vulnerable to an approximate 55-inch sea level rise
- No data
- Priority Development Area
- Major Roads and Highways

0 1 2 3 MILES

NORTH



NOTE: Inundation data from Knowles, 2008. PDA data from ABAG. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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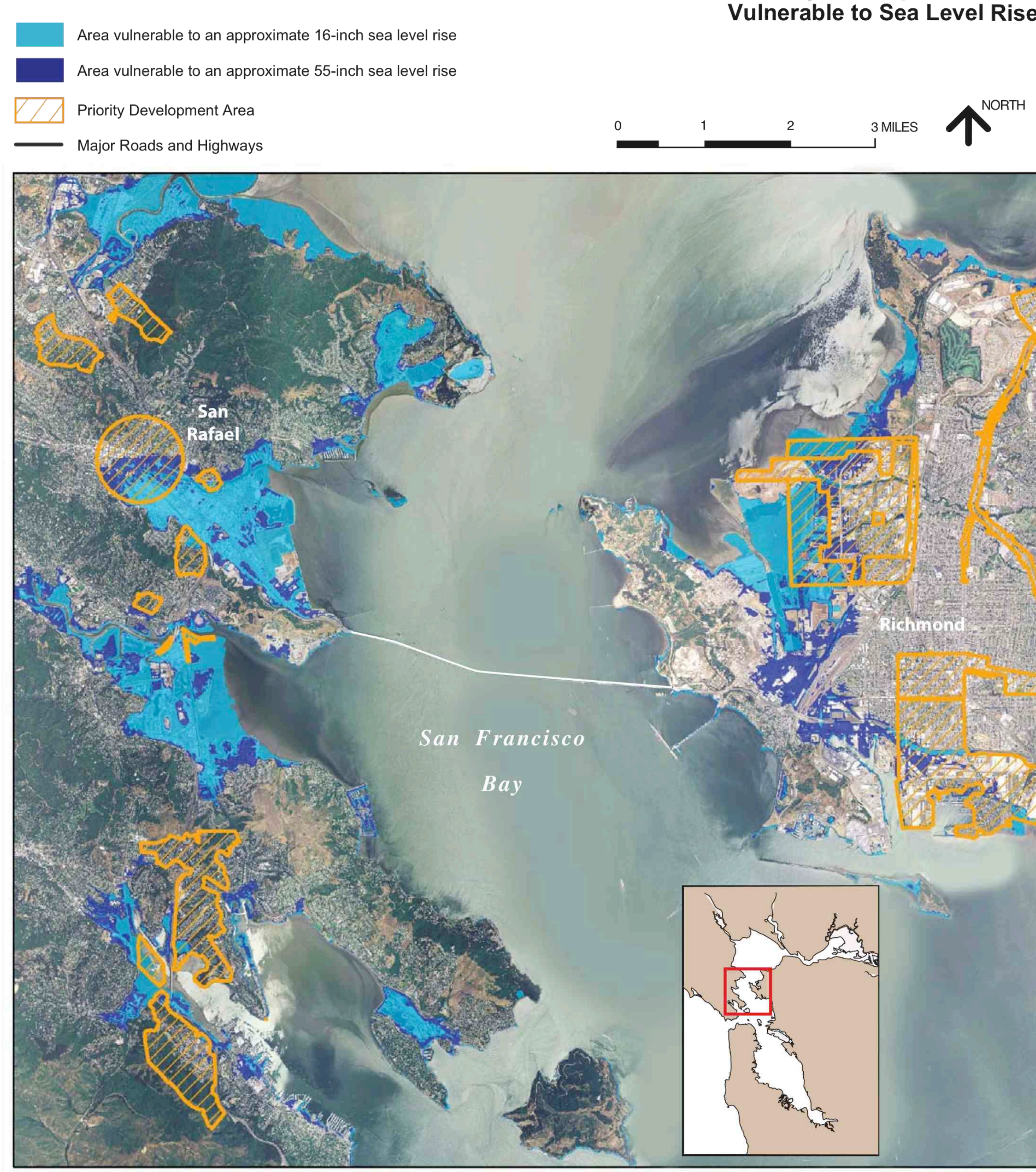
San Francisco Bay
Conservation and Development Commission

Figure 2.2

Central Bay North Priority Development Areas Vulnerable to Sea Level Rise



NOTE: Inundation data from Knowles, 2008. PDA data from ABAG. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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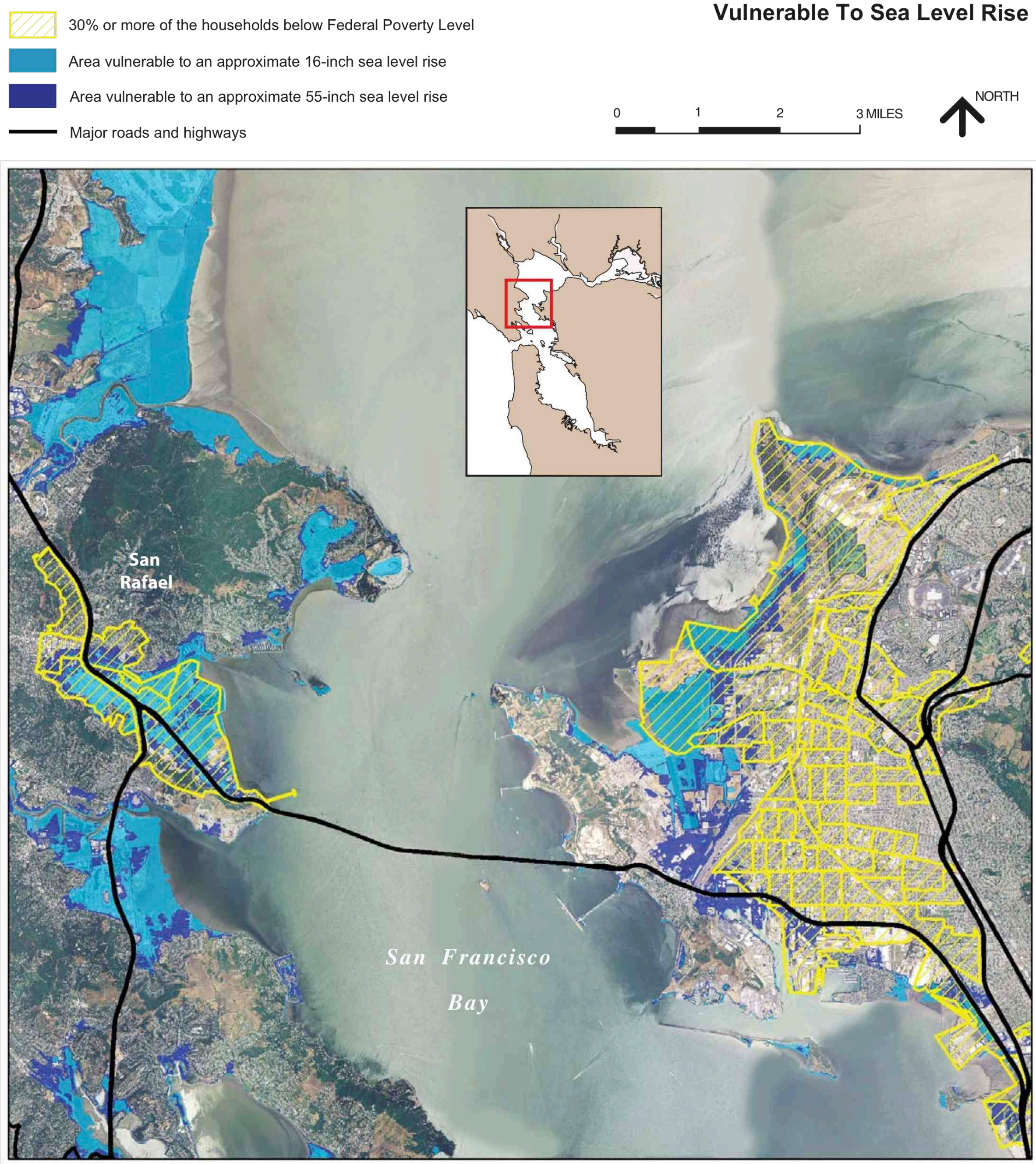
Figure 2.3

**Central Bay North
Low Income Residential Areas
Vulnerable To Sea Level Rise**



NOTE: Inundation data from Knowles, 2008. U.S. Census Bureau, 2000. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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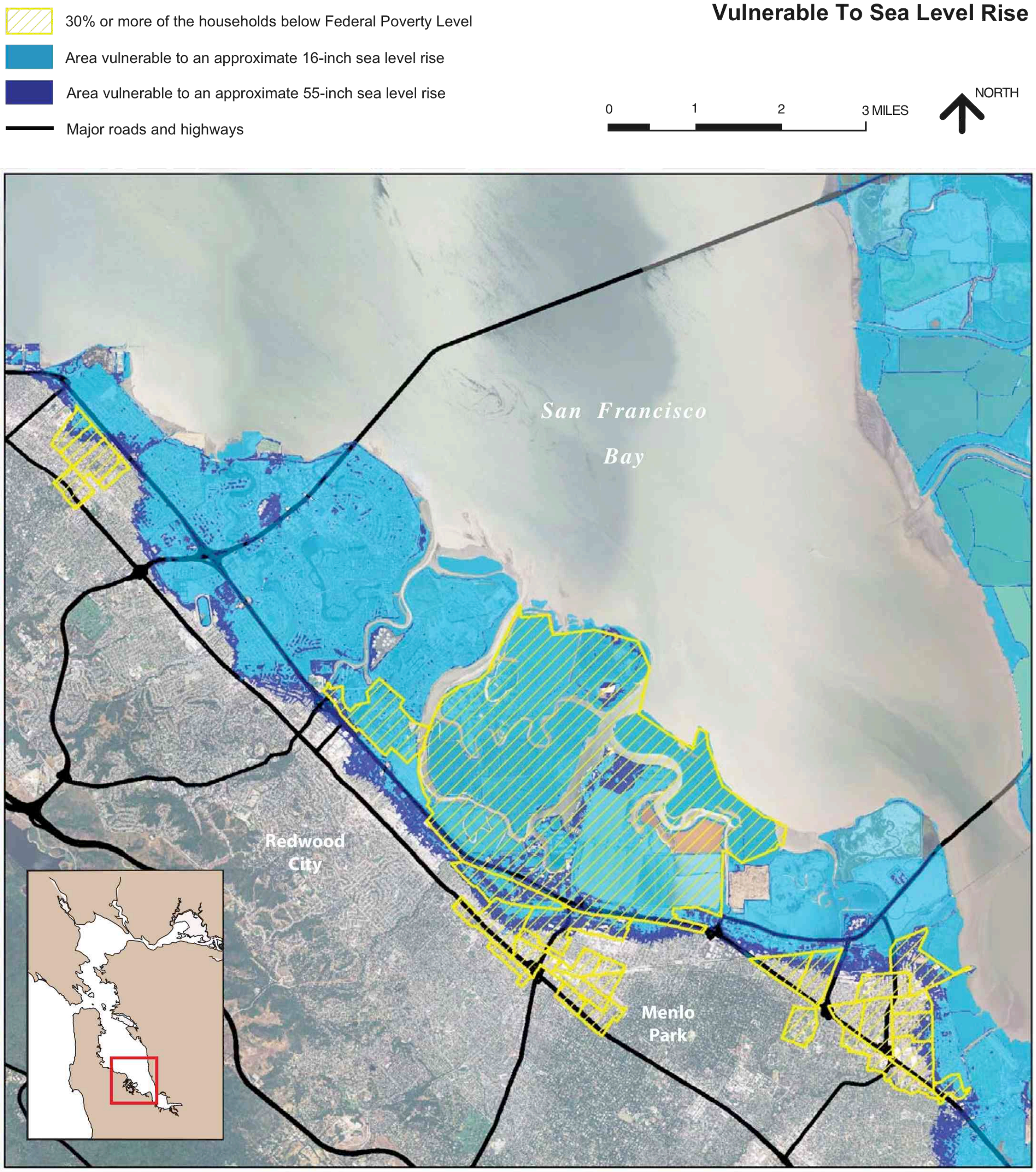
San Francisco Bay
Conservation and Development Commission

Figure 2.4

Central Bay South
Low Income Residential Areas
Vulnerable To Sea Level Rise



NOTE: Inundation data from Knowles, 2008. U.S. Census Bureau, 2000. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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Schools and Emergency Services. Important civic institutions such as schools, fire stations and hospitals are at increased risk of flooding under both sea level rise scenarios. Thirty-five schools are located in the current 100-year flood plain—where the risk of flooding increases substantially by mid-century. That number increases to 81 with 55-inches of sea level rise (Heberger et. al. 2008). Eleven fire stations, nine police stations, and 42 healthcare facilities are vulnerable to 55-inches of sea level rise (Heberger et. al. 2008). The extent to which this could compromise emergency response in an extreme event requires additional attention in coordination with the Federal Emergency Management Agency, cities and counties.

Commercial and Industrial Land Use

In 1969, when the Legislature adopted the Bay Plan into law, it recognized that some regionally significant land uses require a shoreline location. Without protecting shoreline areas for these land uses, there would be future pressure to fill the Bay to accommodate them. Therefore, the Bay Plan designates areas of the shoreline that are suitable for water-oriented priority uses: airports, ports, water-related industry, wildlife refuges and waterfront parks and beaches. Currently there are 86 designated areas comprising over 167,000 acres (260 square miles) throughout the nine county region. These priority use areas help make the Bay Area one of the most economically prosperous, ecologically rich and healthy urban centers in the world and they all will experience some increase in vulnerability related to flooding.

Airports. Two international airports in the region, San Francisco International (SFO) and Oakland International (OAK) are located on the Bay shoreline. These two airports provide important linkages with international and domestic trading partners and serve as major hubs of the national and global air passenger system and air cargo network.

SFO is the principal international air-cargo gateway within the region. In 2007-2008, SFO handled approximately 16 million passengers and approximately 500,000 metric tons of cargo (Airport Commission, City and County of San Francisco, 2008). In 2007-2008, OAK handled approximately 14 million passengers and 600,000 metric tons of primarily, domestic cargo (Oakland International Airport, www.oaklandairport.com, 2008). Air cargo is the fastest growing segment of the goods movement economy and is forecast to triple in the next twenty to thirty years (MTC, 2004).

Both airports have limited land available for expansion of passenger and cargo facilities and runways. Funding for such improvements is limited due to federal budget constraints and the deteriorating financial health of national airlines. The two airports cover approximately 4,700 acres (7.3 square miles) along the shoreline of the Bay. Over 3,400 acres (five square miles) or 72 percent of these designated lands are vulnerable to a 16-inch sea level rise while approximately

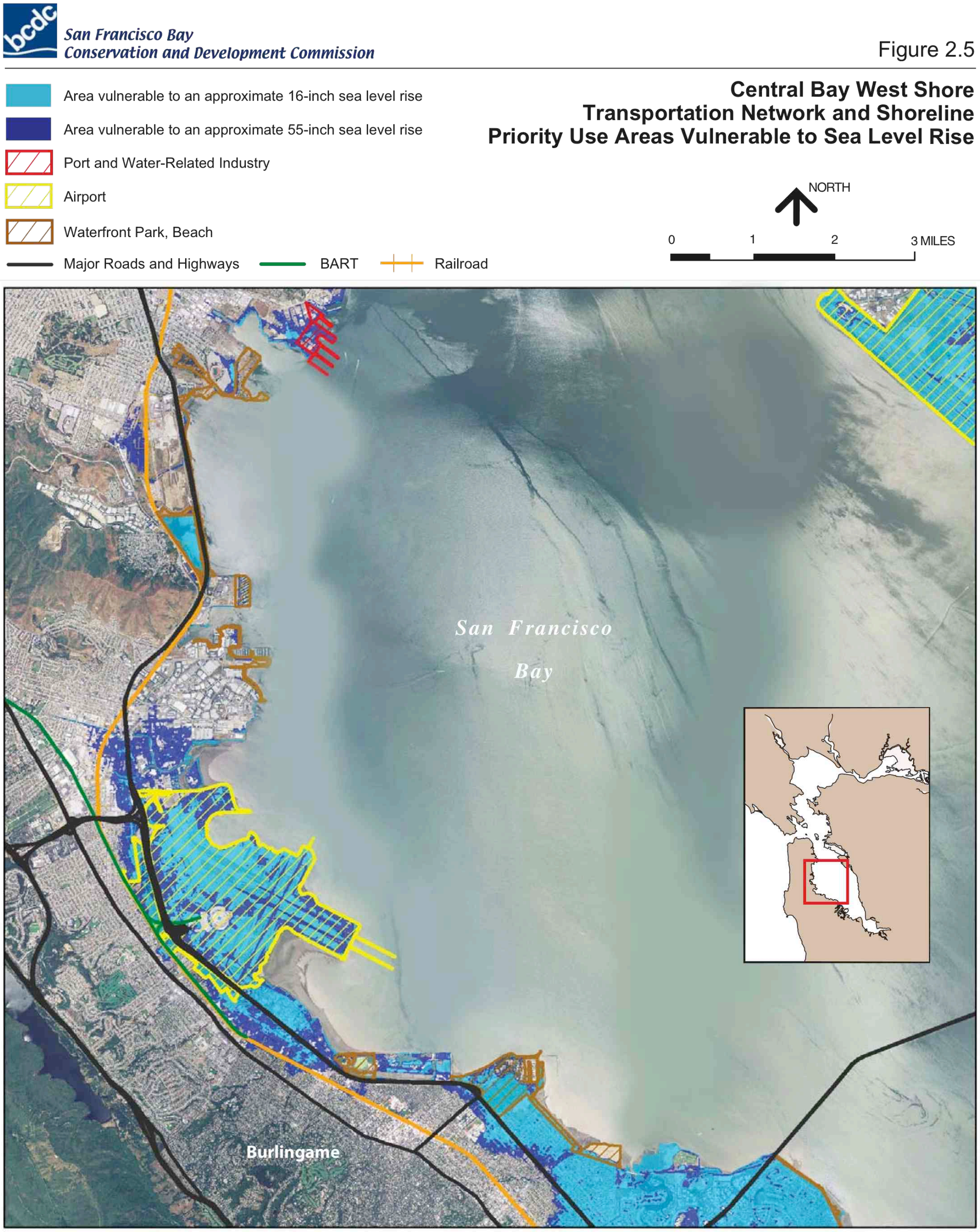
4,400 acres (six square miles) or 93 percent of these designated lands are vulnerable to a 55-inch sea level rise (Figure 2.5). Runways at SFO are particularly vulnerable to flooding, because they have subsided since their original construction. Raising levees around runways will be necessary to protect them from flooding, the cost of which could be as high as $1,085 per foot (Heberger 2008). It may be necessary to raise runway elevations, which would require massive amounts of fill material from the Bay or elsewhere.

Congestion within the highway networks that serve each airport makes airport access difficult for passengers and cargo distributors. SFO is linked to the highway transportation network via the U.S. 101 and also has direct Bay Area Rapid Transit (BART) passenger service. Segments of the U.S. 101 and the BART tracks near the airport are vulnerable to a 16-inch sea level rise. OAK is linked to the region via the I-880 corridor, which is vulnerable to flooding near Port of Oakland and the Bay Bridge approach (Figure 2.6).

The Regional Airport Planning Committee—a collaborative effort between BCDC, the Metropolitan Transportation Commission and the Association of Bay Area Governments—was formed to address regional airport planning issues. During its current update to the Regional Airport Systems Plan Analysis, the committee is analyzing methods to reduce GHG emissions from airports and address the affects of future sea level rise.

Ports. There are five major ports in the Bay Area located at Oakland, Richmond, San Francisco, Redwood City and Benicia. Like the region's airports, the ports rely on the transportation network to move cargo and employees to and from the ports. The ports handle a variety of cargo types, including container cargo, dry bulk, break bulk, neo bulk and liquid bulk. Maritime cargo handled by these five ports was 25,449,892 metric tons in 2006, which is a 60 percent increase since 1994 (BCDC, 2007). The Port of Oakland, the nation's fourth busiest port, handles the largest volume of cargo within the region and currently exports more cargo than it imports. The port generates over 28,500 jobs and $3.7 billion annually for the regional economy (TCIF/MTC, 2008). However, maritime industry revenues have recently decreased.

Commercial, residential, port, and other industrial uses compete for highly desirable shoreline property. Port activities are often perceived as inconsistent with commercial and residential uses and raise concerns over public health and noise. Constituencies are created that may oppose port improvements or expansion due to this perception. However, ports require a shoreline location. In addition to occupying highly desirable land, ports have high maintenance costs and maintenance activities can impact the Bay: maintaining deep-water channels and berths for the movement of large vessels is costly and has adverse impacts upon estuarine ecological communities.



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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San Francisco Bay Conservation and Development Commission

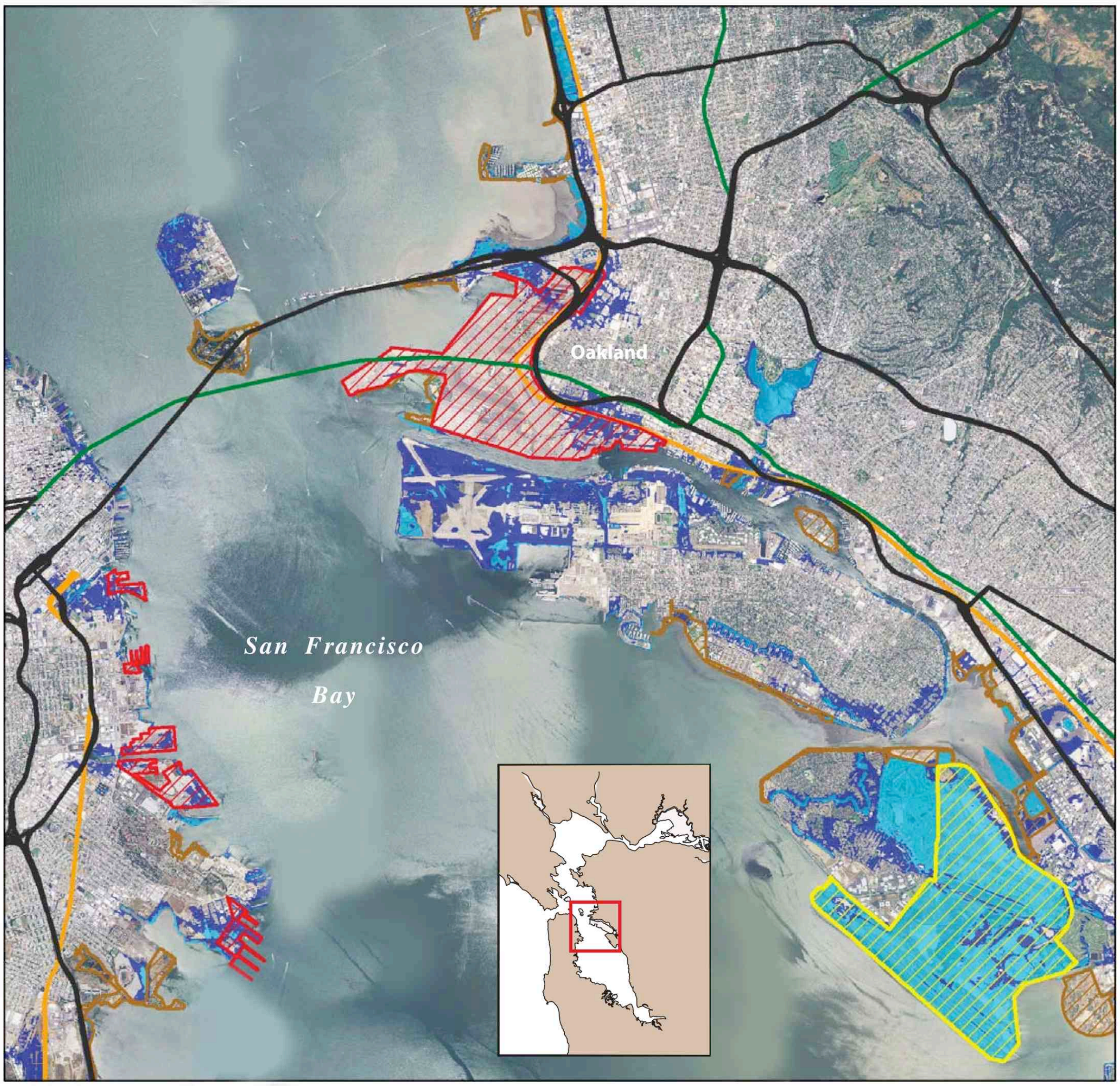
Figure 2.6

Central Bay
Transportation Network and Shoreline Priority Use Areas Vulnerable to Sea Level Rise

- Area vulnerable to an approximate 16-inch sea level rise
- Area vulnerable to an approximate 55-inch sea level rise
- Port and Water-Related Industry
- Airport
- Waterfront Park, Beach
- Major Roads and Highways
- BART
- Railroad

NORTH

0 1 2 3 MILES



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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Shoreline flooding and damage to Bay Area ports as a result of sea level rise would likely have a ripple effect through much of the west coast economy. All of the region's ports are vulnerable in varying degrees to projected sea level rise. Collectively, 2,700 acres (four square miles) of land is designated for port use. Approximately 100 acres (0.1 square miles) or four percent of land within the port areas are vulnerable to a 16-inch sea level rise while approximately 500 acres (0.7 square miles) or 20 percent of land within the port areas are potentially vulnerable to a 55-inch sea level rise. Additionally, segments of the ground transportation network that make vital connections to the Port of Oakland are vulnerable to flooding (Figure 2.6). Several vulnerabilities exists in the Central Corridor—the major trade route in the region, which originates at the Port of Oakland, runs roughly parallel with I-80, and heads toward Sacramento and beyond.

Water-Related Industry. Water-related industries are those that require shoreline locations to receive and process raw materials and distribute finished products via deep water shipping lanes, rail corridors or highways. For example, water-related industrial operations include chemical and petroleum refining and storage, metal refining and fabrication, food processing, mineral resource processing and dredge material handling facilities.

The costs of doing business in the Bay Area ranks among the highest in the nation. These high costs combined with other changes to the region's economy have driven many manufacturing jobs out of the region, resulting in a loss of 11 percent loss since 1995 (Bay Area Economic Forum, 2004). Additional factors that have compromised the competitive advantage of Bay Area industries include, globalization, technology-driven improvements in productivity, a shift away from a manufacturing based economy towards a service-based economy, as well as demographic shifts. (Bay Area Economic Forum, 2004). Like ports, water-related industries occupy desirable shoreline property that is subject to encroachment of mixed-use and residential land use into adjacent areas. Several communities have expressed interest in redeveloping water-related industrial sites with non-industrial development, continuing a trend that has been underway in the region for decades.

Collectively, designated water-related industry lands cover approximately 12,350 acres (19 square miles). Approximately, 2,000 acres (3 square miles) or 16 percent of these designated areas are vulnerable to a 16-inch sea level rise while approximately 3,500 acres (5 square miles) or 28 percent of these designated areas are vulnerable to a 55-inch sea level rise. Future flooding could disrupt the operations of water-related industries and, thus, the provision of important resources to the region. For example, many of the petroleum refineries provide fuel for the region's airports, goods movement and commuters.

Table 2.2. Summary of Land Use Acreages Vulnerable to Flooding

Land Use	Existing Area (acres)	Acreage Vulnerable to Sea Level Rise	
		16 inches	55 inches
Airports	4,700	3,400	4,400
Ports	2,700	100	500
Water-related Industry	12,350	2,000	3,500
Total	19,750	5,500	8,400

Public Health Impacts of Climate Change

Sea level rise is just one of many potential impacts of climate change on the San Francisco Bay region. Climate change is likely to impact public health in the region by changing conditions such as air quality, heat events, water quality and the distribution of vectors and infectious diseases. The populations most vulnerable to impacts include those who are already ill, children, the elderly and the poor (Luers et. al. 2006). The state currently experiences the worst air quality in the nation and over 90 percent of the population lives in areas that exceed either the ozone or particulate matter air quality standards. Ozone and particulate matter combined, contribute to over 8,800 deaths and $71 billion in health related costs per year (Luers et. al. 2006). Higher temperatures will exacerbate air pollution by increasing the frequency, duration and intensity of conditions that lead to air pollution formation. Other factors such as wildfires contribute to unhealthy air quality conditions. In the summer of 2008, regional air quality was directly impacted by wildfires, which are expected to increase in frequency under climate change conditions.

Heat events are also likely to be more intense, last longer and occur earlier in the year relative to historical events (1961-1990) (Dreschler et. al. 2005). Higher temperatures can lead to increased risk of death from factors such as heat stroke (exhaustion, dehydration and respiratory distress). Coastal cities may experience a larger proportional increase in summer heat compared to inland cities. Furthermore, coastal populations are not as adaptable to high heat as inland populations, which are more likely to be able to cope with heat stress because they have already adapted to frequent and extreme heat (Hayhoe et. al. 2004, Kalkstein, 2003).

Water quality impacts on the Bay can affect Bay Area residents. Marine processes that affect the Bay ecosystem (Chapter 3) are impacted by temperature increases and sea level rise, which can kill phytoplankton, alter fresh and salt water mixing and upwelling, and disrupt primary productivity. Impacts upon these processes could lead to algal blooms and hypoxia, which could impact water quality.

Other public health impacts could include the potential for expansion of the range of infectious diseases and vectors as a result of changing environmental conditions. Vector borne disease may become a public health concern as the life cycles of organisms such as mosquitoes, ticks, fleas and rodents change as a result of climate change. Waterborne disease occurrences linked to storm runoff from heavy rainfall, flooding, and sewage overflow could become a health concern (Dreschler et. al. 2005). However, predicting the impacts of vector borne diseases is challenging due to the multiple interactions between climate, host and vector organism, vector control programs and public response to control programs.

Other Shoreline Land Uses, Infrastructure and Institutions

Beyond the land uses that have been discussed in this chapter, there are other regionally important shoreline land uses, infrastructure, and institutions that may be vulnerable to future coastal flooding. These include water and sewage treatment plants, flood control channels, landfills, contaminated sites, pipelines, power transmission lines, schools, fire stations and hospitals.

Wastewater Treatment Facilities. Most of the Bay Area's water and swage treatment facilities treat wastewater and sewage that is discharged in the Bay. There are 22 wastewater treatment plants on the shoreline that are vulnerable to a 55-inch rise in sea level (Heberger et. al. 2008), many of which lack the capacity to handle current storm flows resulting in frequent sewage spills. Without modifying these facilities, more frequent storms associated with sea level rise will increase the number of spills in the Bay. Many treatment plants rely on gravity to discharge treated water into the Bay. As Bay water levels rise, this mechanism could fail and significantly impact facility operations. Inundation into treatment facilities can disrupt operations or damage pumps and related machinery. Should Bay waters exceed the elevation of plant intake structures, saltwater intrusion into treatment facilities will alter biotic conditions necessary for the breakdown of waste material. Sea level rise will likely require significant investments to retrofit or relocate some sewage treatment plants. Although the Commission's law requires that new fill, such as intake structures, must minimize impacts to water quality, the San Francisco Bay Regional Water Quality Control Board has primary authority over water quality in the Bay.

Flood Control Channels. In addition to the rivers and creeks that feed the bay there are a number of flood control channels that drain upland areas. Sea level rise and potential changes in the precipitation patterns may alter the flow dynamics of these channels. With higher water levels and more extreme storm events, Bay water will intrude further into flood control channels making it more difficult for fresh water to drain rapidly from upland areas. This will increase flood risks in locations further upstream. More precise identification of upland areas near creeks and flood channels where this type of flooding may occur is needed for addressing future flood risks. Exploring alternative methods of flood control may be necessary.

Contaminated Lands. Prior to BCDC's creation, many municipalities filled the Bay for disposal of garbage and waste materials. These landfills contain contaminants and toxins. Some are still in operation while others have reached capacity, have been closed and converted to other shoreline land uses, such as waterfront parks. Higher sea levels and extreme storm events will cause flooding and erosion that may impact the integrity of shoreline landfills and release contaminated leachate, adversely impacting ecosystems and public health.

In addition, there are a number of shoreline areas that contain contaminated land as a result of past industrial uses that were more common along the shoreline over the past century. For example, many of the retired shoreline military sites contain contaminated lands that have yet to be fully remediated. Many sites have been remediated with their wastes encapsulated onsite, under the assumption that they would remain upland and dry. If these sites become flooded or eroded, they could release contaminants. While extensive and ongoing efforts have been made to remediate contaminated sites around the Bay, it will be imperative to address this issue before contaminated sites begin to be impacted by sea level rise.

Pipelines and Transmission Lines. Numerous pipelines and power transmission lines cross under the Bay, cut across wetlands, and parallel the shoreline, distributing water, petroleum and energy. Transmission towers sit on footings within the Bay, which must be constructed at elevations so that towers are either above high tide or can withstand increased exposure to corrosive salt water. The footings must also be engineered keep towers standing through extreme storm events.

Pipelines carry petroleum products across important wetlands, including the Suisun Marsh—one of the largest habitats on the Pacific Flyway, which is at great risk of flooding under both the 16-inch and 55-inch scenarios. In 2004, a 14-inch-in-diameter pipeline ruptured and discharged 123,774 gallons of diesel fuel oil into the marsh damaging approximately 224 acres (0.3 square miles) and injuring a variety of birds, small mammals, fish, reptiles, and aquatic and terrestrial invertebrates (Kinder Morgan 2008). The California Department of Fish and Game's Office of Oil Spill Prevention and Response (OSPR) was instrumental in containing the spill. To prevent future pipeline spills that could be caused by rising sea level, OSPR and regulatory agencies must ensure that pipelines traversing the Bay, wetlands, and vulnerable uplands are retrofitted to withstand higher water levels or relocated.

The Regional Transportation Network

The Bay Area relies heavily upon its transportation network. Central to the quality of life enjoyed by residents and the region's overall economic prosperity, is an interconnected network of railroads, major roads and highways, BART, ferries and bicycle lanes. These transportation elements allow for the movement of goods within the region and with domestic and international trading partners, while providing mobility to residents by getting them from their houses to their jobs, and to recreational areas. Residents travel within the region by a variety of modes. In 2000, 83 percent of all trips within the region were made by auto, 10 percent by walking, 5 percent by transit and 2 percent by bicycle (MTC staff, 2009).

Transportation-dependent industries, such as ports and airports, employ almost half of the workers in the region. Goods-producing businesses spent approximately $8.6 billion on transportation in 2000 (MTC, 2004). The major roads and highways and rail network serve to link the regional ports and airports with inland markets including the important Central Valley agricultural economy. Projections for goods movement within the Central Corridor indicate that by 2016 goods movement along the corridor is projected to grow to approximately 90 million tons and will be valued at $101 billion (TCIF/MTC, 2008).

The transportation network also provides mobility to residents and includes the Bay Area Rapid Transit (BART) system, the regional rail and ferry network, sidewalks, trails, and a regional bike network. The BART system spans 104 miles, contains 43 stations and carries an average of 357,000 riders every week (BART, 2008). Passenger rail service is provided by a number of operators including Amtrak, Altamont Commuter Express (ACE) and Caltrain. Ferry service is provided by the Golden Gate Highway Transportation District, Blue and Gold Fleet, Vallejo Baylink, and Harbor Bay Maritime. As of 2001, annual ridership exceeded over 4,000,000 passengers and has been steadily increasing in the last decade (WTA, 2003). Bicycling within the region has also been increasing and a network of bike lanes is being linked to the public transportation network. Certain Bay Area cities have higher percentages of bike ridership including, Berkeley (4.9 percent) and Palo Alto (5.8 percent), when compared with the rest of the nation (0.1 percent) (U.S Census Bureau 2000 and MTC, 2001).

Major Roadways and Highways. Although the Bay is an essential part of life in the Bay Area, it is sometimes viewed an impediment to the mobility of goods (BCDC, 2005), requiring bridges to cross its water and long stretches of highway to traverse the shoreline. Trucks move most goods within the region, making major roads and highways a critical component of the goods movement network. This network supports local businesses that require delivery of supplies for production and finished products to consumers. Goods producing industries contribute $213 billion to the regional economy and account for 37 percent of the region's industrial output (MTC, 2004). Many of the major nodes of the goods movement network, such as ports and airports, are situated on the shoreline and are connected to producers and consumers via the road network. Four primary road corridors, I-880, I-580, I-80 and U.S. 101 handle 80 percent of the goods movement within the region. These roadways serve to link the major economic centers of the region, including San Francisco, Oakland, San Jose and Silicon Valley, thus providing mobility to the region's work force while also providing access to region's open space and myriad recreational opportunities.

The regional road and highway network is highly congested and many critical components of the network need repair. The congestion on Bay Area freeways, as measured by the daily vehicle hours of delay, has increased significantly from approximately 25,000 hours in 1981 to just over 160,000 (Caltrans District 4 HICOMP, 2008). Many of the major roads and highways, such as I-80 in Berkeley and U.S. 101 in the South Bay are situated between highly urbanized communities and/or critical infrastructure and the Bay, which constrains options for the expansion of the existing network. In other parts of the region, such as Highway 37 in the North Bay, the major roads and highways are situated between the Bay and sensitive wetland communities. Avoiding adverse impacts on Bay resources creates additional challenges and constraints for road expansion and maintenance projects to address the current maintenance needs and relieve congestion. Where rising sea level and storm activity do not actually flood roads and highways, it will further complicate maintenance and congestion relief projects.

Because of their proximity to the Bay, many of the major roads and highways within the region may be significantly impacted by sea level rise and extreme flooding events. Approximately 99 miles of the major roads and highways within the region are vulnerable to a 16-inch rise in Bay water levels and approximately 186 miles of major roads and highways are vulnerable to a 55-inch rise. Interstate 880 along the eastern shoreline of the South Bay, U.S. 101 in Santa Clara, San Mateo and Marin Counties, Highway 37 in the North Bay, I-680, and Highway 12 in Solano County include significant portions of roadway that are vulnerable to flooding (Figure 2.5-2.7).

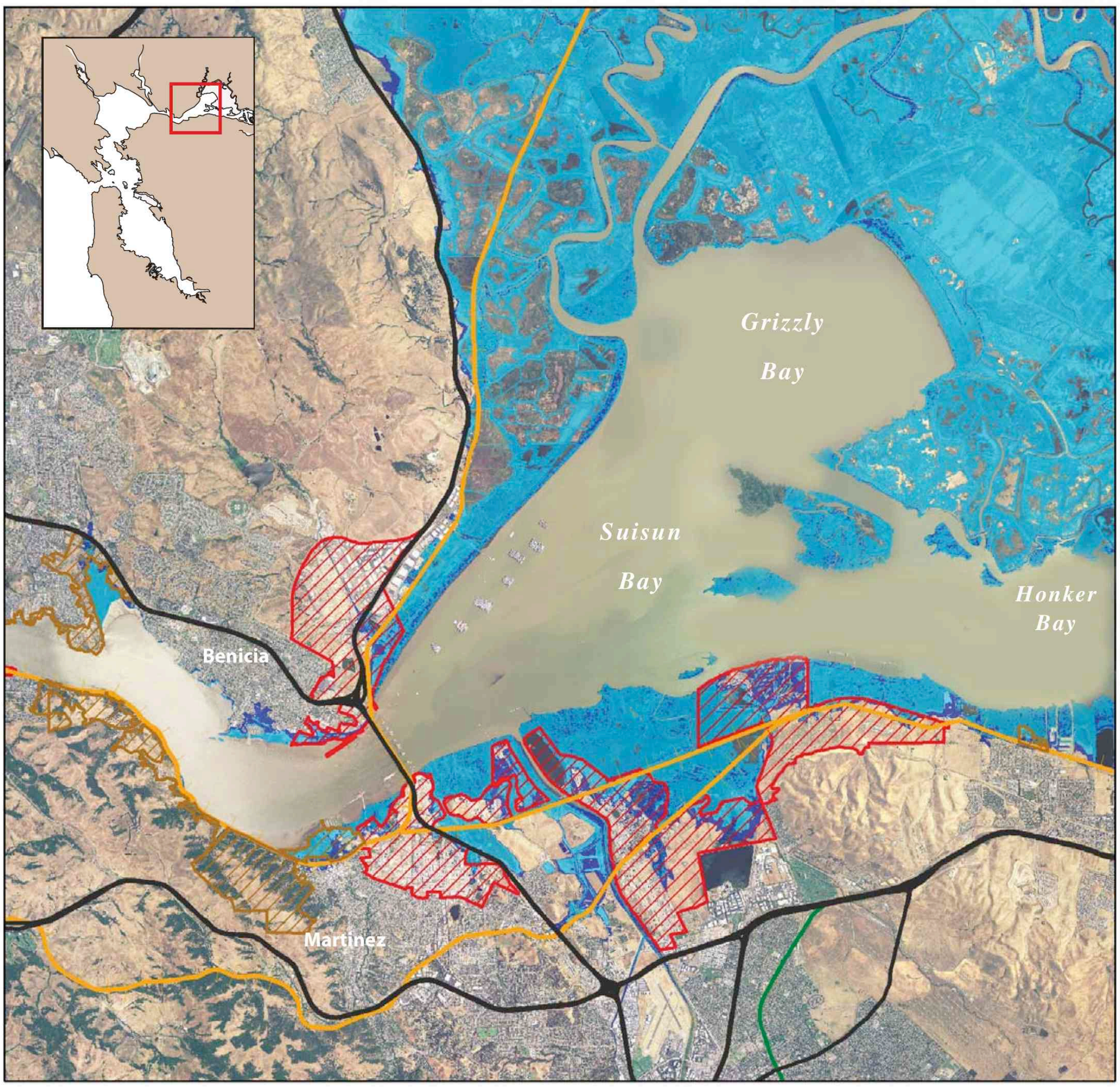
Figure 2.7

Grizzly Bay
Transportation Network and Shoreline Priority Use Areas Vulnerable to Sea Level Rise

- Area vulnerable to an approximate 16-inch sea level rise
- Area vulnerable to an approximate 55-inch sea level rise
- Port and Water-Related Industry
- Waterfront Park, Beach
- Major Roads and Highways
- BART
- Railroad

NORTH

0 1 2 3 MILES



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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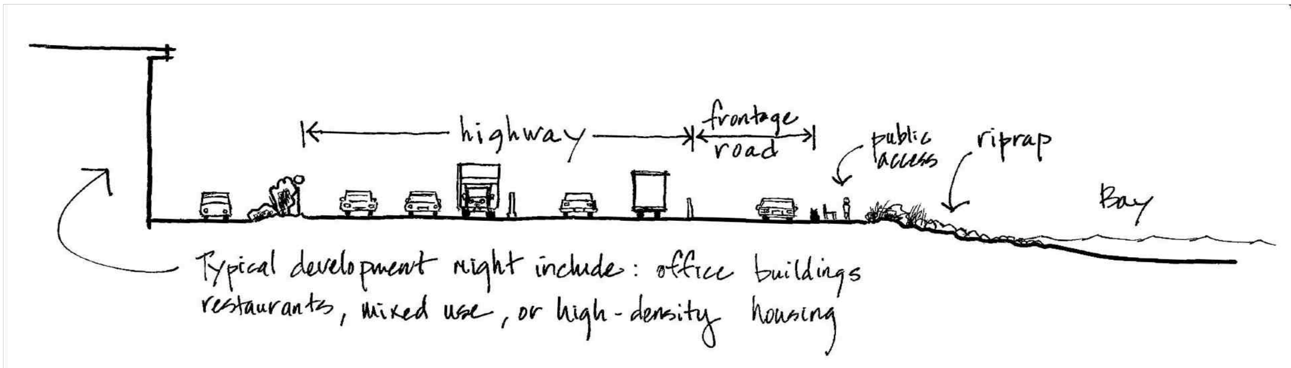
Figure 2.8 Typical Section: Highway Adjacent to the Bay

Source: BCDC

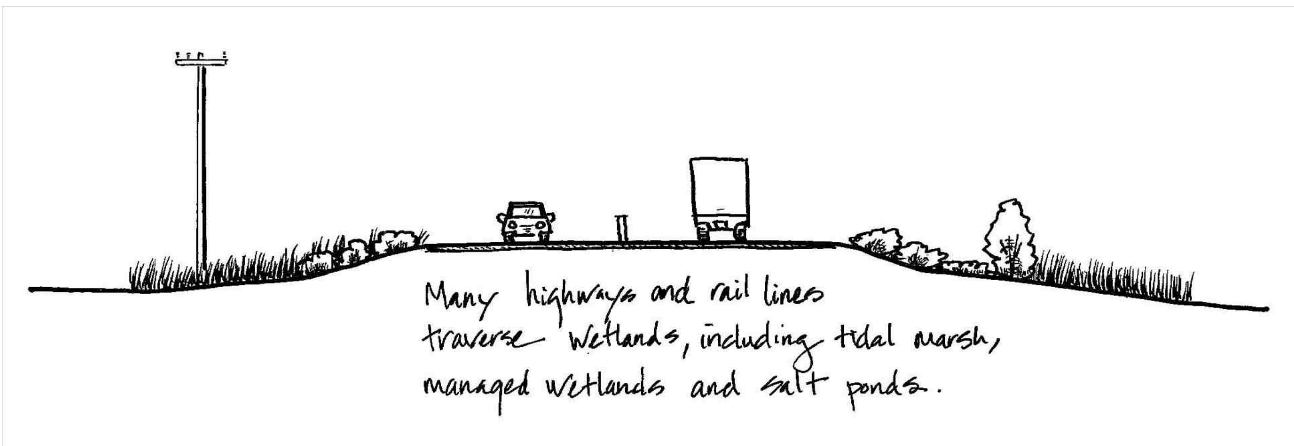


Many roads and highways will be subject to secondary impacts from sea level rise. For example, much of 1-80 along the Berkeley and Albany shoreline is not directly subject to flooding due to the existing elevation of the roadway (Figure 2.8). However, erosion from increased storm activity can undermine existing protective and/or highway structures, which can substantially increase the cost of maintaining the highway. Other secondary impacts may occur where traffic from one impacted road is diverted onto another road. Increased construction activity that is necessary to make transportation infrastructure more resilient to sea level rise can cause more congestion and impact residential communities adjacent to roadways. Congestion causes delays in the movement of goods throughout the region and adds time to residents' already lengthy commutes. Finally, the supporting structures of many of the region's bridges may be susceptible to unanticipated, prolonged contact with corrosive salt water.

Rail Network. The regional rail network has more than 600 miles of track, moves vast quantities of freight and passengers, and links the region with the Central Valley and inland areas (BCDC, 2005). Leading products moved by the rail system include, steel, waste, scrap, petroleum products, crushed stone and automobiles. (MTC, 2004). Freight service is provided by two Class I rail carriers, Union Pacific (UP) which links the region with Roseville and the Central Valley, and Burlington Northern Santa Fe (BNSF) which links the region to Stockton and beyond. Many water-related industries, including oil refineries and auto terminals located along the shoreline of the East Bay rely heavily upon rail service. There are a number of locations along the rail network that link multiple transportation sectors. For example, intermodal areas are located near the Ports of Richmond and Oakland. These ports rely heavily on rail to transport inbound cargo containers to inland processing and manufacturing locations. Likewise, the rail network serves to bring cargo from inland locations for export to trading partners.

Passenger service links the major jobs centers in San Francisco, Oakland and San Jose with other Bay Area cities and towns and with inland cities in the Central Valley such as Sacramento and Stockton. The primary passenger rail service providers include, Bay Area Rapid Transit (BART), San Francisco MUNI, Caltrain, Amtrak's Capitol Corridor, and Altamont Commuter Express (ACE). BART is an especially critical component of the region's passenger rail network, providing commuter service for residents in Alameda, Contra Costa, San Francisco and San Mateo counties.

Figure 2.9 Typical Section: Highway or Rail Line Through Wetlands
Source: BCDC



Except for BART ad MUNI, Bay Area railroads use the same tracks for both passenger and freight service, which creates significant congestion. At-grade rail crossings slow traffic on rail and surface roads. Furthermore, freight demand is expected to grow upwards of 350 percent over the next 50 years (MTC, 2007) and many of the rail lines are in highly urbanized areas where options for major modifications or expansion are limited. Other stretches of rail are bordered by sensitive Bay habitats and ecological communities, which further constrain options for rail expansion (Figure 2.9).

Approximately 70 miles of railroad are vulnerable to sea level rise of 16-inches while 105 miles are vulnerable to a 55-inch sea level rise. The rail segments that are particularly vulnerable to flooding include, the Central Corridor where it passes through the Suisun Marsh (Figures

2.7), the tracks along the northern Contra Costa shoreline near Martinez, the Caltrain corridor on the Peninsula, the ACE, and Capitol Corridor in the South Bay. Because these rail segments are shared by multiple users and already experience congestion, flooding could paralyze rail service regionwide. The economic impacts of a system-wide rail failure would be staggering. Furthermore, protection of this infrastructure from sea level rise will also be costly and may require funds to be redirected from projects that address current pressures on the system.

Waterfront Parks and Beaches

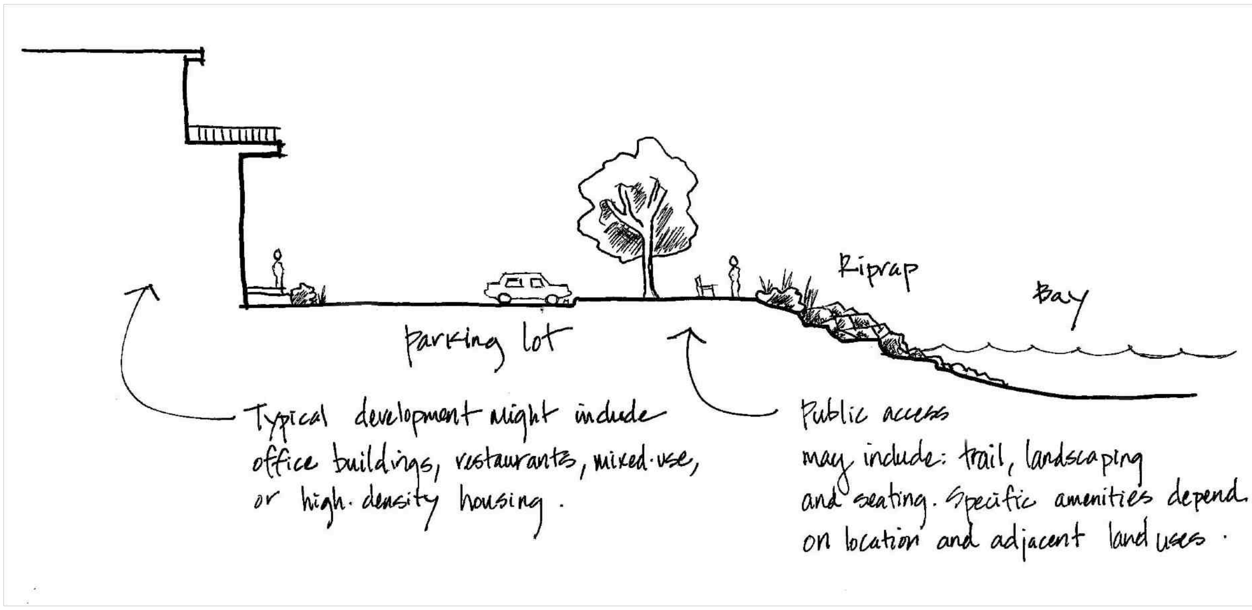
Waterfront parks and beaches promote enjoyment of the Bay, the region's most important open space, and enhance the quality of life for Bay Area residents. Recreation on the shoreline and in the Bay foster a life-long bond between residents and the Bay, improves their health, and provides a respite from the stress of living in a high-paced urban environment (BCDC, 2006). Recreational opportunities can be found at beaches, parks, marinas, shoreline trails and water trails, boat launches and fishing piers. People use waterfront parks, beaches, and public access to hike, bicycle, kayak, swim, fish or just watch the sunset.

The region has an average of approximately 95 acres (0.1 square miles) of open space per 1,000 residents, much of which is located in hills surrounding the Bay (BCDC, 2006). Available open space and recreational lands may not be able to keep pace with the region's growing population. In the 1990's, population grew at two percent while the addition to the open space only grew at 1.1 to 1.6 percent per year (Bay Area Open Space Council, 1999). Creating shoreline recreational opportunities that reflect the diversity in race, culture, age and income levels is another important challenge. Some communities, particularly on heavily urbanized parts of the shoreline, lack sufficient open space and recreational lands. Many of the waterfront parks and beaches are the most accessible recreation areas to the highly urbanized and diverse communities along the shoreline. Prospects for expanding shoreline and Bay recreational opportunities are further limited by their proximity to sensitive habitat, the cost of purchasing shoreline property, and the long-term maintenance and operations expenses. In many cases, remediation of contaminants may also increase the costs of converting some sites to waterfront parks.

Approximately 23,000 acres (35 square miles) are designated in the *San Francisco Bay Plan* as waterfront parks and beaches. Approximately 3,250 acres (5 square miles) or 14 percent of the region's waterfront park and beach areas are located in areas vulnerable to a 16-inch sea level rise. A 55- inch sea level rise would impact approximately 4,300 acres (6 square miles) or 18 percent of the region's waterfront parks and beaches. As sea level rises, it will become more costly to maintain existing waterfront park and beach areas as well as to provide new recreational opportunities to meet the demands of a growing population. Furthermore, use of shoreline areas may increase as temperature increases as a result of high-heat days. Finally, providing recreational opportunities along the shoreline that do not adversely impact sensitive ecological communities will likely contribute to the challenges of providing and maintaining shoreline recreational opportunities in the future, especially if sea level rise reduces the viability of Bay habitats.

Figure 2.10 Typical Section: Public Access

Source: BCDC



BCDC-Required Public Access

Another defining feature of the region's shoreline is the abundant and diverse public access opportunities that ring the Bay. Public access includes physical access to and along the shoreline as well as visual public access to the Bay from other public spaces. Shoreline public access includes waterfront parks, promenades, piers, trails, plazas, overlooks, and connections linking public streets to the Bay. BCDC has required shoreline public access as part of shoreline development since 1969. Every proposed shoreline development must provide "maximum feasible public access, consistent with a proposed project." As a result of BCDC permit requirements, there are 700 sites that provide over 300 miles of public access to and along the approximately 1,000 miles of Bay shoreline. Public access generates regional benefits that are similar to waterfront parks and beaches. However, public access areas are usually smaller and associated with some type of development (Figure 2.10).

San Francisco Bay
Conservation and Development Commission

Figure 2.11

Central Bay North
BCDC - Required Public Access
Vulnerable To Sea Level Rise

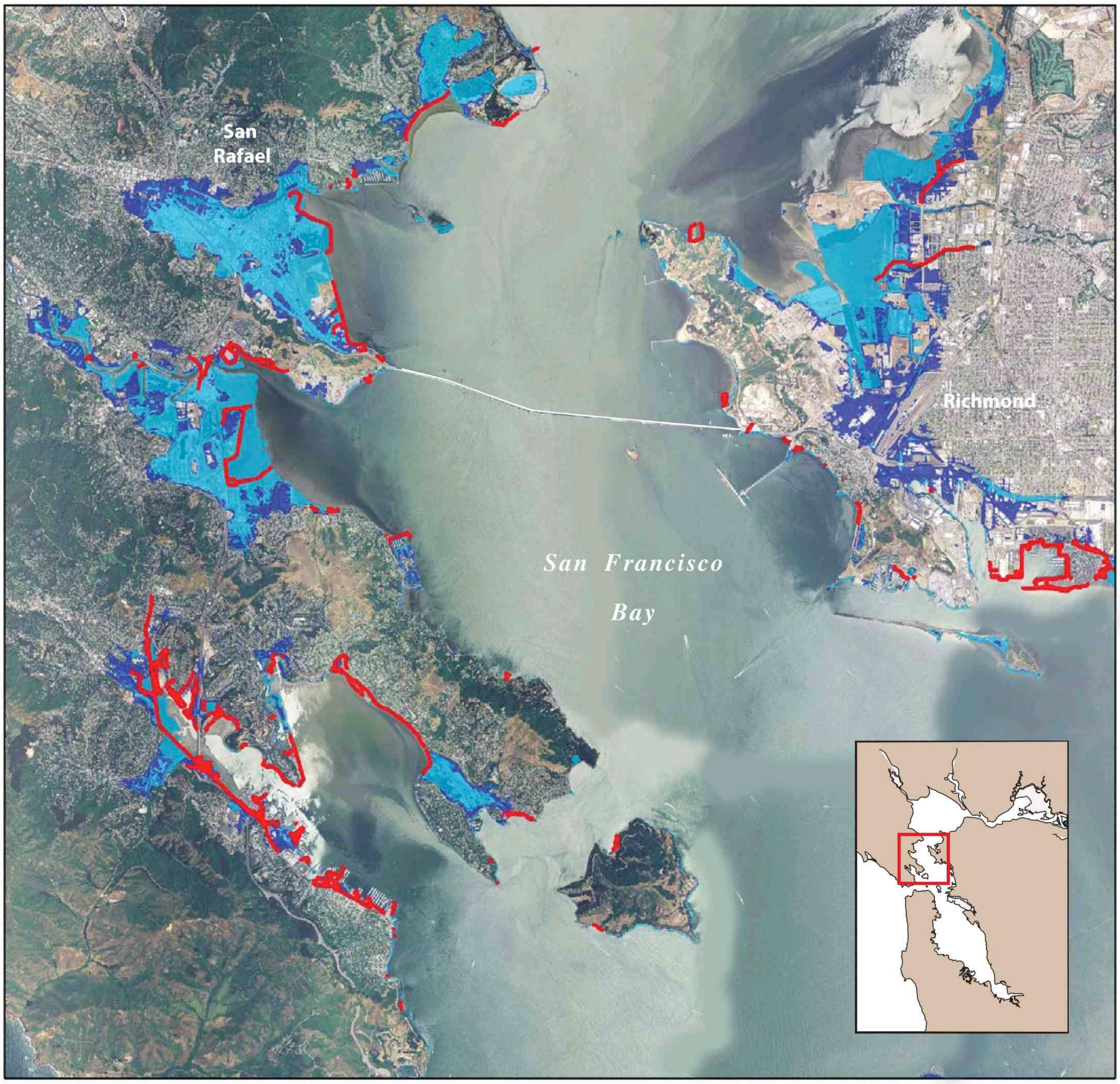
Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise

BCDC - Required public access

0 1 2 3 MILES

NORTH



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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San Francisco Bay
Conservation and Development Commission

Figure 2.12

Central Bay West Shore
BCDC - Required Public Access
Vulnerable To Sea Level Rise

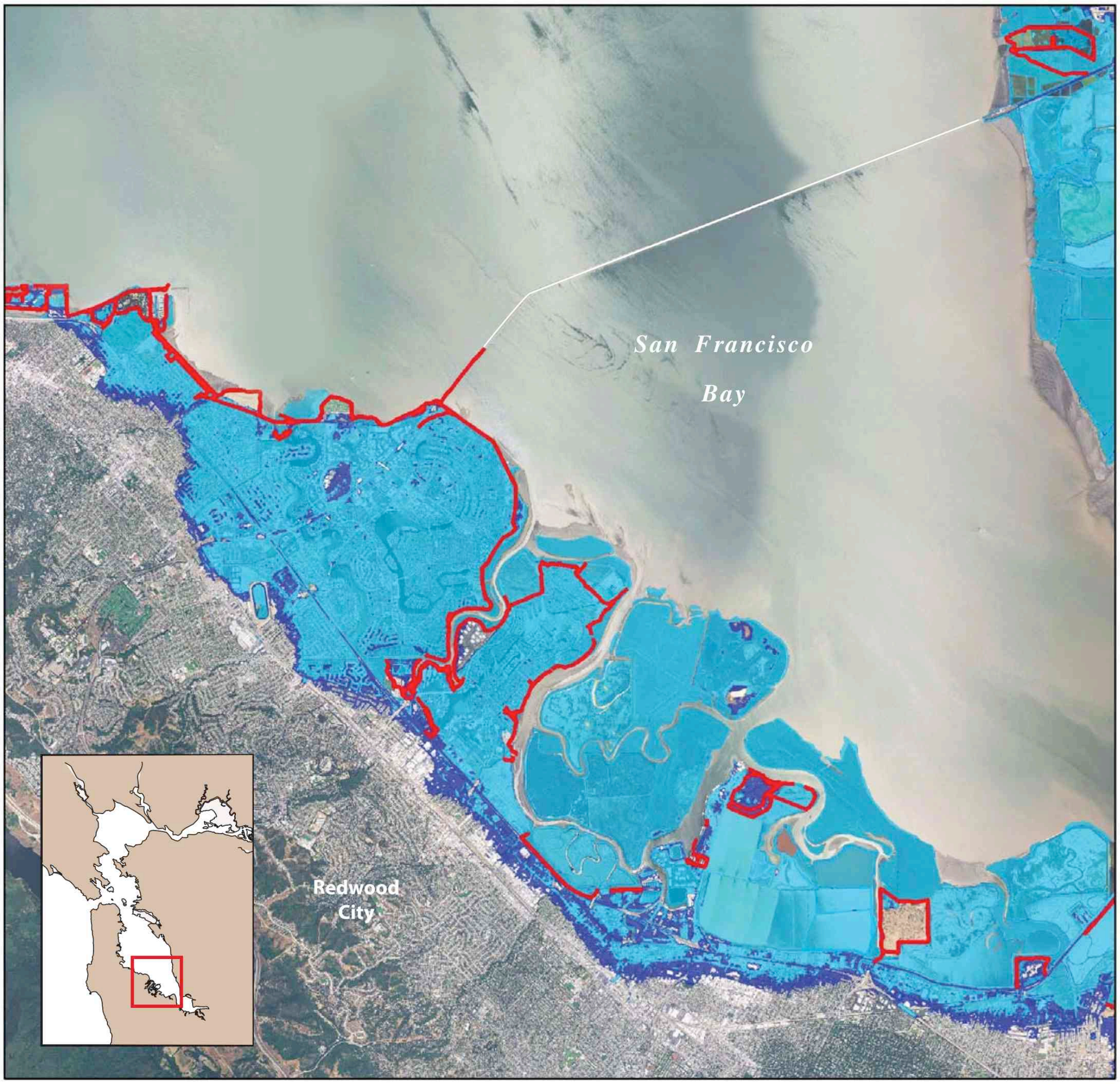
Area vulnerable to an approximate 16-inch sea level rise

Area vulnerable to an approximate 55-inch sea level rise

BCDC - Required public access

0 1 2 3 MILES

NORTH



NOTE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Inundation data does not account for existing levees or other shoreline protection. Aerial imagery is NAIP 2005 data.

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Many of the public access areas required by BCDC are also components of the San Francisco Bay Trail, which is a project to provide a recreational trail around the entire Bay. Some of the public access required by BCDC is part of a network of trail heads providing on-water access for non-motorized small boats and sail craft—the San Francisco Bay Area Water Trail.

The vast majority of public access is located within the Commission's 100-foot shoreline band jurisdiction (100 feet from the Bay) and, therefore, vulnerable to flooding from sea level rise and storm activity. Over 400 public access sites, or approximately 57 percent, are located in areas that are vulnerable to a 16-inch increase in sea level rise. Over 616 locations, approximately 87 percent, are located in areas vulnerable to a 55-inch increase in sea level rise (Figures 2.11 and 2.12). Public access located on elevated structures, such as fishing piers, bridges and wharves is not included in these estimates. The impacts to elevated public access features will largely depend on factors such as their design and construction as well as the resilience of the adjacent shoreline.

The increased likelihood of flooding will require difficult choices regarding the location, design and maintenance of existing and future public access. In urban areas, locating public access further inland may not be feasible. In open space areas, wildlife communities require adequate space and buffers to respond to sea level rise, which will further constrain public access siting and design options. Where structural shoreline protection is required, raising existing or constructing new structures may block physical and visual access to the Bay, especially where land has subsided. Access stairs or ramps to the top of shoreline protection structures may be necessary to provide access to the Bay. The widespread impacts to the region's existing public access will limit opportunities to provide a sense of visual continuity and connectedness for public access.

Summary and Conclusions

Residents, businesses and entire industries that currently thrive on the shoreline are subject to flooding by the middle of the century, and probably earlier. By mid-century, shoreline development located in the current 100-year flood plain will be subject to flooding from not just a 100-year flood, but from a high tide. A summary of these vulnerabilities is provided in Table 2.3. Approximately half of that development is residential, totaling 66,000 acres (103 square miles). Over 82,000 acres (128 square miles) of residential development is vulnerable to flooding by the end of the century. Where residents are not directly vulnerable to flooding, access to important services such as commercial centers, health care, and schools would likely be impeded by flooding of the service centers or the transportation infrastructure that links them.

Rising sea levels can impact the delivery of petroleum products, electricity, and drinking water to Bay Area residents and businesses. The range of impacts can be more difficult for low-income residents because they generally have less financial flexibility and fewer resources to pursue alternative housing and transportation.

Table 2.3 Summary of Shoreline Vulnerabilities

Shoreline Uses	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
Residential	Significant residential acreage and disproportion-ate amount of low-income residents.	Widespread flooding of approximately 270,000 residents and 82,000 residential acres (128 square miles).	High- Lost investments and/or relocating residents has major financial and social repercussions. Low-income residents are especially sensitive.	Medium- for those with the resources. Low- for low-income residents.	High
Airports	Subsided runways at SFO. Difficulty moving goods on land from SFO & OAK.	Flooding of 72-93% of acreage for airport operations. Secondary impacts to ground movement of cargo and passengers from flooding of transportation network.	High- Airports are critical to the regional economy. They are especially sensitive to primary and secondary impacts of flooding.	High- Shoreline protection for runways and upgrading important ground transportation is costly, but would likely be a high regional priority.	Medium-High
Ports	Difficulty moving goods via highways and rail.	Moderate flooding of ports (4-20% of total acreage). Most flooding impacts regional goods movement.	Medium-High- Ports are central to the regional economy. Rail lines and highways essential to goods movement are sensitive to flooding.	Medium- Goods movement is central to port activities. Ports are unlikely to be burdened with the cost of transportation infrastructure.	Medium-High
Water-related Industry	High business costs and job loss. Competing shoreline uses.	Localized flooding, that is especially troubling for individual sites (16-28 percent of total acreage)	Medium- The industry is already losing jobs, but flooding is localized rather than widespread.	Medium- Flood damage or new shoreline protection would be concentrated in a few areas.	Medium

Continuation of Table 2.3 Summary of Shoreline Vulnerabilities

Shoreline Uses Continued	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
Major Roads and Highways	Congested and in need of repairs.	Widespread flooding (99-186 miles), including key highways and interchanges.	High- Many highways are adjacent to the Bay and cross the Bay. Flooding projected on some key passenger and truck routes.	Medium- Current congestion and maintenance issues make costly adaptations difficult.	High
Rail	Congested with multiple users sharing single tracks.	Widespread flooding (70-105 miles of track), including key segments.	High- Rail lines carry passengers and freight, are located on low-lying lands, and wetlands. Freight demand projected to grow	Low- Current location of tracks limits options for expansion or modifications..	High
Waterfront Parks and Beaches	Bay Area population is growing faster than recreational opportunities. Expensive shoreline property limits potential conversion to waterfront parks.	Moderate flooding relative to other shoreline uses (14-18 percent of waterfront parks). Beaches receive widespread flooding.	Medium- Waterfront parks provide a unique experience that requires a shoreline location, but will experience moderate flooding.	Low There are few available locations for waterfront parks.	Medium-High
Public Access	Public access is required on a project-by-project basis, making regional coordination challenging.	Widespread flooding of most public access (57-87 percent of public access sites).	High- Public access is not currently designed or sited to address flooding.	Low- Public access is unique to the shoreline. As the shoreline moves, public access must be designed to move with it, but upland movement may be blocked by development.	High

As temperatures increase, shoreline communities may experience a larger proportional increase in summer heat compared to inland communities, which can lead to heat stroke.

Water quality will suffer if wastewater treatment facilities are flooded from sea level rise and storm activity. Compromised water quality and higher temperatures can result in algal blooms and a higher potential for the spread of water-born vectors.

Large commercial and industrial areas are vulnerable to flooding, especially in San Francisco, Silicon Valley, and Oakland. Approximately 72 percent of the San Francisco and Oakland airports is vulnerable to a 16-inch sea level rise and 93 percent is vulnerable to 55 inches of sea level rise, which can disrupt the transport of as much as 30 million passengers and approximately one million metric tons of cargo. Flooding of highway segments in the regional transportation network can disrupt the movement of goods from ports, which handled approximately 25 millions metric tons of cargo in 2007-2008. Other water-related industries would be similarly affected. Flooding of the rail system would be particularly serious, since multiple users share a single line in most locations around the Bay.

The Bay is a magnificent body of water that helps sustain the economy of the western United States, provides great opportunities for recreation, nourishes fish and wildlife, affords scenic enjoyment and in countless other ways helps to enrich our lives (Bay Plan, 2008). It is central to many activities in the region, whether traveling by car or rail along the shoreline, landing at an airport, strolling along the shoreline, or watching the fog stream in on a summer's day. Waterfront parks and public access provide opportunities to enjoy the Bay and remind us of its place in the region. There are 23,000 acres (35 square miles) of waterfront parks, of which 14 percent is vulnerable under the lower scenario and 18 percent is vulnerable under the higher scenario. Fifty-seven percent of the public access required by BCDC is vulnerable under the low scenario and 87 percent is vulnerable under the high scenario. The decline of waterfront recreational opportunities will impact the quality of life in the Bay Area and could affect the region's deep connection to the Bay.

To address the widespread flooding from storm activity and sea level rise, shoreline protection projects will be needed. Shoreline protection can be structural, natural, or a combination of both. Choosing the appropriate form of shoreline protection—one that both protects public safety and minimizes ecosystem impacts—is critically important. In the long-term, the region needs to engage in an open and vigorous public dialogue to make the difficult decisions about what to protect, and where and what kind of new development is appropriate in vulnerable areas, and areas where further development should be avoided.

CHAPTER 3
The San Francisco Bay Ecosystem

The San Francisco Bay, the largest estuary along the Pacific shore of North and South America, is constrained in its ability to adapt to climate change by the intensity of human uses in and around the Bay. The close proximity of urban and industrial development to the Bay dramatically reduces the adaptive capacity of the ecosystem and limits the potential for restoring additional habitats that could otherwise compensate for altered temperature, salinity, and sediment systems. The Bay provides many benefits to the surrounding human community while supporting numerous plants, animals, and migratory birds who feed on fish and shellfish (BCDC 2002). Maintaining these ecosystem benefits must be a key element of the region's climate change adaptation strategy.

Tidal wetlands provide critical flood protection and improve water quality by reducing and preventing shoreline erosion, and filtering pollutants from surrounding areas. Tidal wetlands also store carbon in their soils (Mitch and Gosselink 2000, Trulio et. al. 2007), which may help to mitigate climate change by sequestering GHGs. Tidal salt marshes in the South Bay sequester between 54 – 385 grams of carbon per square meter per year (Patrick and DeLaune 1990), an amount equivalent to at least 6,000 gallons of gasoline emissions (EPA 2005). Greco Island, one of the oldest tidal salt marshes in the Bay, sequesters 150- 250 grams of carbon per square meter per year and has been doing so for at least 100 years (Callaway and Drexler, unpublished, cited in Trulio et. al. 2007).

In many locations, humans have altered, degraded, or eliminated these ecosystem benefits. Roads, levees, dredging, and urban development have fragmented and destroyed much of the once contiguous shoreline habitats of the Bay. Sand mining, shell mining and dredging activities have altered subtidal habitats. There are now 40,000 acres (62 square miles) of tidal marsh, a reduction of 80 percent since the late 1800s. Similarly, tidal flats have been reduced up to 60 percent to 29,000 acres (45 square miles) from bay fill and erosion. Only seven out of an estimated 23 miles of former sandy beaches remain (Goals, 1999).

The existing Bay ecosystem is largely a managed environment. Elements of the Bay ecosystem continue to withstand pressures from climate change and human alteration, exhibiting remarkable resiliency. The adaptive capacity of the Bay ecosystem to withstand the rapid climate changes predicted for the next century depends both on the magnitude of impacts resulting from climate change and the management actions taken in response to those impacts. Further habitat loss resulting from climate change and future construction of levees and other flood protection infrastructure along the shoreline would threaten the survival of critically endangered species and natural communities. The challenge is to preserve the appropriate amount and diversity of habitats to maintain healthy species populations, while, at the same time, finding sustainable flood protection solutions for shoreline development and industry. Retaining the benefits that the Bay ecosystem provides will require a new management approach that recognizes the dynamic nature of the ecosystem. While past management strategies for the Bay ecosystem focused on conserving a static ecosystem or restoring a previous ecological state, new strategies must be based on anticipating future conditions, such as accelerating sea level rise, and implementing adaptive management as the ecosystem evolves over time.

Sea Level Rise in the Bay Ecosystem

Under current sea level conditions, the ebb and flow of the tides inundates the intertidal mudflats (tidal flats) and low to middle tidal marshes at the edge of the Bay on a regular basis, while storms and other extreme weather events cause occasional flooding of high marsh and upland areas. Low-lying areas behind levees also are flooded occasionally when levees are overtopped or fail due to storms, earthquakes or burrowing animals. The lower of the two sea level rise scenarios (16 inches) is sufficient to impact 90 – 95 percent of the existing tidal marshes and tidal flats by changing the frequency and duration of inundation. Of these tidal marsh areas, almost 20 percent exist lower in the tidal zone, which makes them vulnerable to permanent submersion and erosion (PWA and Faber 2004, Pacific Institute 2009). A 16-inch rise in sea level would also permanently flood approximately 70 to 75 percent of the subsided wetlands in Suisun Marsh if their fragile levees were to fail. The few remaining beaches (about 45 acres or 0.07 square miles) on the margin of the Central Bay are all vulnerable to sea level rise. Increased frequency and duration of inundation in some areas and permanent flooding of other areas induced by sea level rise would initiate a number of complex physical, ecological, and biological responses in estuarine ecosystems, which, when combined with other impacts of climate change, would increase the vulnerability of the Bay ecosystem. While wetlands can adapt to sea level rise, given sufficient sediment and room to migrate, armoring of the shoreline and other human impacts may hamper or prevent this and result in more loss of tidal marsh habitats.

Constraints to Wetland Adaptation. The shape of the Bay-Delta estuary formed over the past 3,000 years in response to gradual sea level rise and the circulation of sediment by tides, waves, and inflowing rivers (Byrne et. al. 2001, Wells and Gorman 1994, Atwater 1979). The Bay-Delta estuary now supports a mosaic of habitats, extending from the subtidal water column where fish live to the tidal flats and tidal marshes. Tidal wetlands not only protect the shoreline from the flooding and erosive effects of storms, but also provide a setting for the surrounding communities to connect with the Bay ecosystem. Accelerated rates of sea level rise may outpace sedimentation in tidal flats and tidal marshes, which would lead to erosion and drowning of these habitats in the Bay-Delta estuary.

Tidal flats in the Bay are already eroding as a result of insufficient volumes of sediment from tributary watersheds. The area of tidal flats in the North Bay decreased by 68,000 acres (106 square miles) over the period from 1951-1983, and 4,500 acres (7 square miles) in the South Bay between 1858 and 2005 (Jaffe et. al. 2007, Jaffe and Foxgrover 2006). The decline in sediment flowing into the Bay is the result of dam construction, flood control, water diversions and other management actions in the tributary watersheds.

Early studies estimate as much as 80 to 90 percent of the sediment reaching the Bay came from the Sacramento and San Joaquin rivers (Krone, 1979; Porterfield, 1980). During the Gold Rush era, hydraulic mining in the Sacramento and San Joaquin watersheds resulted in approximately 35 trillion cubic yards of sediment being deposited in the Bay and a 60 percent increase in the area of tidal flats over the period from 1856 to 1887 (Jaffe et. al. 2007). Much of this mining sediment contains mercury, which was used to extract gold and is now widespread in Bay sediment. Under some conditions, such as increased acidity, the inorganic mercury in this sediment can be converted to methylmercury, a highly toxic form.

In 1884, the California Supreme Court (Sawyer Decision) outlawed the discharge of mine tailings to rivers. This decision dramatically reduced the volumes of sediment that were coming from the Sacramento and San Joaquin watersheds by the early 1900s (Porterfield, 1980), despite the ongoing logging, urbanization, and agricultural development, activities that typically cause soil erosion. A primary cause for the continued sediment decline during the 20th century was the construction of dams for water supply that prevented sediment from reaching the Bay (Krone, 1979; Ogden Beeman and Associates and Krone and Associates 1992).

From the 1940s to the 1970s, the damming of rivers trapped sediment in both the Sacramento and San Joaquin watersheds and local tributaries of the Bay (e.g., Napa River, Sonoma River, and Alameda Creek). Damming also reduced flood flows, limiting the capacity of rivers to transport sediment from the Delta to the Bay (Porterfield, 1980; McKee et. al. 2006;

Wright and Schoellhammer, 2004). Now, research demonstrates that sediment from local tributaries to the Bay may constitute as much as 43 percent of the annual sediment delivered to the North Bay (McKee et. al. 2006), and the loss of tidal flats is an indication that the Bay watersheds are contributing less sediment.

Subsidence of diked areas further complicates the restoration of tidal wetlands which would aid the Bay's ability to adapt to sea level rise. Sites planned for tidal marsh restoration are, in many cases, subsided two to six feet below mean sea level (e.g., South San Francisco Bay) (PWA and Faber 2004, Watson 2004, Poland & Ireland 1969, Orr et. al. 2003), which is substantially lower than the elevation at which marsh plants usually grow. A fundamental component of tidal marsh restoration is the recruitment of native plants, which thrive under specific flooding conditions that are controlled by their elevation with respect to the tides. The target elevation can be achieved by placing dredged material on site or by promoting natural sediment deposition through re-suspension and transport of muddy sediment from tidal flats. Once an adequate elevation is reached, marsh plants tend to colonize the site and initiate organic matter accumulation, which aids the tidal marsh in keeping up with sea level rise (PWA and Faber 2004, Orr et. al. 2003). Regional partnerships such as the Long-Term Management Strategy (LTMS) for dredged material from the San Francisco Bay Area (LTMS Plan 2001) are already working to address the decline in sediment supply by maximizing the beneficial use of dredged material for wetland restoration.

However, higher rates of sea level rise may jeopardize efforts to restore tidal wetlands and maintain the current form of the Bay-Delta estuary. Erosion of subtidal areas may also expose mercury-laden sediment and impact circulation patterns in the Central Bay, possibly contributing to scour of bottom sediment, a primary physical control on habitats in subtidal regions of the Bay (NOAA 2007). The erosion of tidal flats and tidal marshes would result in additional loss of recreational, flood protection, and water quality benefits.

In order for estuarine migration to occur, gently sloping areas of transitional habitat containing a combination of wetland and upland features are needed. These wetland-upland transition zones are high in species diversity and also provide refuge for endangered species like the salt marsh harvest mouse and the California clapper rail during high tides. These areas could potentially evolve into tidal marsh habitat as sea level rises. However, wetland-upland transition zones have been almost entirely eliminated due to development of the Bay shoreline in close proximity to the upland edge of tidal habitats. In many areas, the upland-wetland transition zone consists of only a few feet of vegetation along the steeply sloping side of a levee.

Salinity Change in Tidal and Subtidal Habitats. Higher salinity due to climate change will stress plant communities and species of concern in the Bay, and some may not thrive or persist in the face of this impact (Callaway et. al. 2007, Spalding and Hester, 2007). Climate change has the potential to impact estuarine salinity in three main ways: (1) changes in total precipitation; (2) changes in seasonal patterns of precipitation and runoff, i.e., a shift from snow to rain and earlier snowmelt; and (3) sea level rise.

These salinity shifts may be moderated or exacerbated by management of reservoirs and water diversions (Callaway et. al. 2007). Water managers rely on freshwater conditions in the Delta to preserve drinking water supplies for the growing populations of the Bay area and Southern California, as well as the agricultural lands and brackish habitats of Suisun Marsh. These goals are accomplished by releasing water from reservoirs during spring, summer, and autumn when there is less rainfall and higher temperatures.

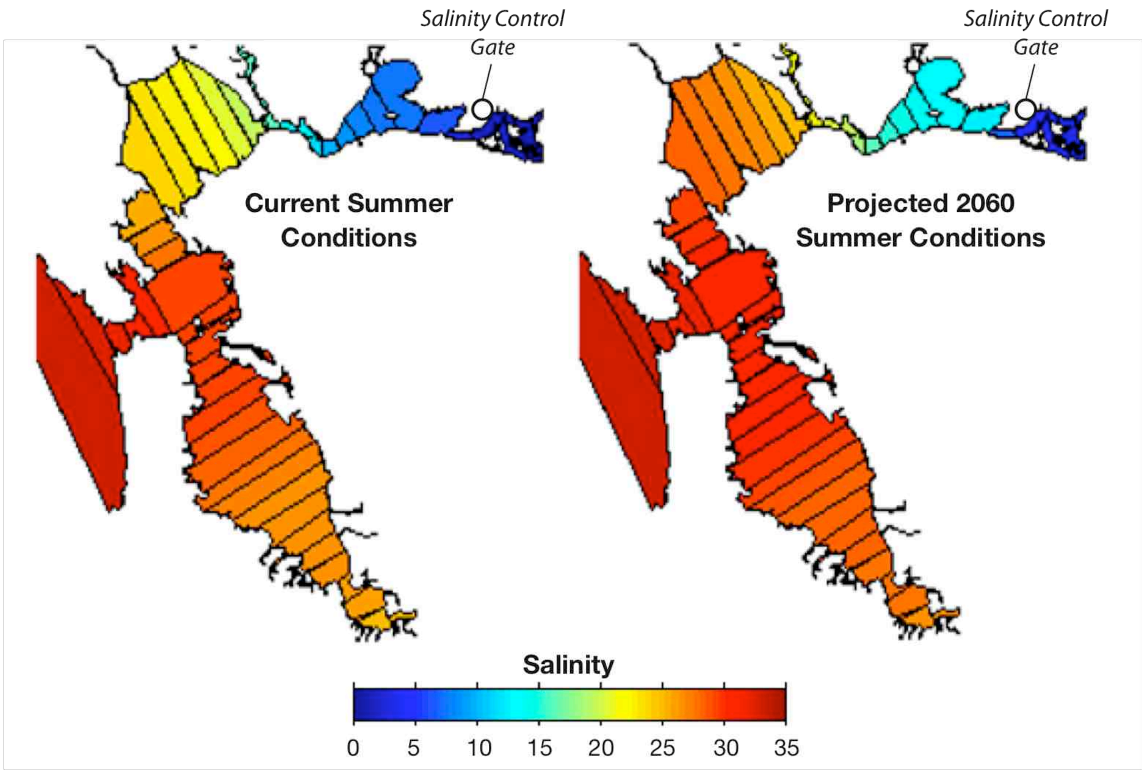
California's water reservoirs are designed with the assumption that a large portion of the state's water will be stored in the snowpack. Warmer temperatures associated with climate change are projected to result in more precipitation falling as rain instead of snow in the winter, causing a 50 percent loss of the Sierra snowpack by 2090. Warmer temperatures will also melt the snowpack earlier in the year (Figure 3.2) (Knowles and Cayan 2002). Earlier snowmelt would require water managers to release excess water from reservoirs, causing more water to flow into the Suisun Marsh and the Bay following winter storms and reducing flows at other times of the year (Barnett et. al. 2008). For example, spring flows (April-June) are expected to decline from 36 percent of total annual flow in 2030 to 20 percent of total annual flow in 2090 (Knowles and Cayan 2002)

The shift in freshwater flows from spring to winter is projected to increase salinity in the South Bay, San Pablo Bay, and especially Suisun Marsh (Knowles and Cayan 2002). Infrequent flushing from the tides in high marsh areas, especially during summer months make these areas particularly vulnerable to salinity shifts (Callaway et. al. 2007). High marsh areas are particularly important because they contain many of the rare and endangered species that are found in California tidal marshes (Baye et. al. 2000).

Salinity increases due to climate change may dramatically impact the brackish and freshwater marshes found in Suisun Marsh and near the confluence with Bay tributaries. Since brackish and freshwater tidal marshes tend to be more productive and provide habitat for a greater diversity of plants than salt marshes, elimination of these valuable wetlands or their conversion to salt marshes could reduce the habitat available to rare and endangered species (Callaway et. al. 2007, Newcombe and Mason 1972, Baye et. al. 2000, Lyons et. al. 2005).

Figure 3.2 Salinity Change in San Francisco Bay

Source: Dr. Noah Knowles



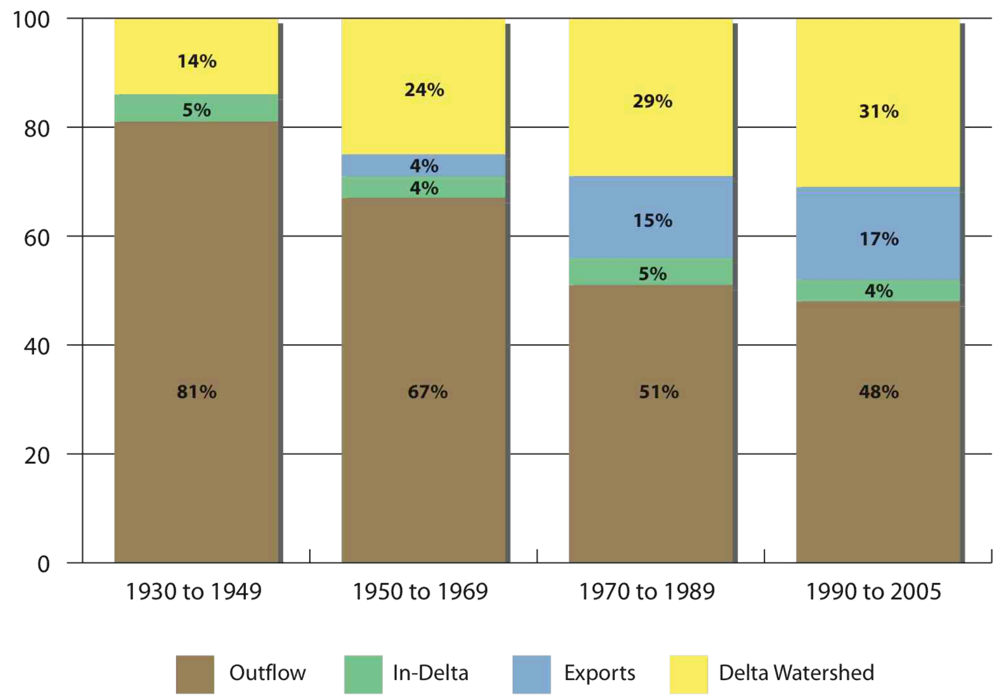
Wet-Year summer salinity field shifts upstream 10-15km due to reduced spring/summer snowmelt runoff

Efforts to use water control structures, such as salinity gates, to artificially reduce salinity in Suisun Marsh in dry years are likely to become increasingly difficult in the face of climate change. The Suisun Marsh Salinity Control Gates (Figure 3.2) restrict the flow of higher salinity water from incoming tides and retain low-saline, Sacramento River water from the previous outgoing tide. An eastward shift of the salinity gradient caused by sea level rise will likely reduce opportunities for importing freshwater into the Suisun Marsh.

These impacts from climate change heighten an already complex debate over water management. The state and federal water projects, upstream water use, and in-Delta water use have reduced the total volume of water entering the Bay. Flows from the Sacramento-San Joaquin Delta (Delta) account for about 90 percent of freshwater flows to the Bay, while ten percent of flows come from the watersheds surrounding the Bay (San Francisco Estuary Project, Aquatic Habitat Institute 1991). A comparison of annual averages from the years 1930-1949 and the years 1990-2005 shows that outflow from the Delta to the Bay has been reduced from 81 percent to 48 percent of total flows (Figure 3.3) (Delta Vision 2008).

Figure 3.3 Changes to Freswater Inflow to the Estuary

Source: DWR



To address the impacts of water diversions, the United States Environmental Protection Agency (EPA) and United States Fish and Wildlife Service (FWS) established a water quality standard for salinity, referred to as X2, to ensure adequate minimum freshwater inflow to the Bay to benefit the reproductive success and survival of the early life stages of many estuarine species[6] (Kimmerer 2002). The X2 measurement corresponds to the upstream location of the mixing zone of fresh and salt water and moves eastward or westward, both seasonally and from year-to-year, depending on the volume and timing of freshwater inflow. The standards require X2 to be maintained at particular locations within the Delta and Suisun Bay between February and June, depending on the amount of precipitation.

The anticipated impacts from climate change and the increasing demand for drinking water and agriculture will limit the ability of water managers to maintain the X2 standard. Inability to maintain X2 may contribute to the extinction of fish species, some of which are a vital economic resource. Fish, such as the threatened Delta smelt and endangered salmon, rely on higher flows in winter and spring, which may be difficult to maintain with less water available in reservoirs (Kimmerer 2002).

Other Water Quality Impacts

Increases in air temperature, salinity, and changes in precipitation and runoff patterns will impact both the Pacific Ocean and the tributaries flowing into the Bay, threatening water quality and human health. Warmer air temperatures may prevent cool waters in the Pacific Ocean, rich in oxygen and nutrients, from circulating to the surface and to various parts of the California coast, including the Bay (Roemmich & McGowan 1995, Harley et. al. 2006). When combined with numerous new and existing pollutants and altered tidal circulation, these effects may produce algal blooms resulting in reduced water oxygen levels.

The increased carbon dioxide concentrations in the atmosphere that are causing global warming are also causing the world's oceans to become more acidic. This is because carbon dioxide dissolves into ocean water and increases acidity. Levels of acidity in the ocean may exceed any found in the 200-300 million year fossil record (Caldeira & Wickett 2003, Feely et. al. 2004, Harley et. al. 2006) This impact may endanger most of the world's coral reefs.

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[6] X2 is defined as the distance upstream from the Golden Gate Bridge to the point where daily average salinity at 1 meter from the bottom is 2 parts per thousand (Jassby et. al. 1995).

High carbon dioxide levels will increase the acidity of Bay waters as well. Although the effects on the Bay are unknown, high levels of acidity may prevent organisms from forming shells and skeletons of calcium carbonate because of a chemical reaction that dissolves calcium carbonate into its constituent ions when acidity is high (Doney et al, 2009). In the Bay, it could particularly impact organisms at the base of the food web that form carbonate shells, such as bivalves, crustaceans and copepods.

Invasive Species

Climate change may influence the potential for new and existing invasive species to become established and spread in the Bay, resulting in a loss of biodiversity and native species that are vital to our economy (e.g., salmon). Warmer air temperatures and increases in salinity may produce conditions better suited to exotic or invasive species, or new diseases that native species are not equipped to resist. The spread of invasive species would further impact one of the most highly invaded estuaries in the world (Cohen and Carlton 1998).

Invasive species already greatly impact tidal and subtidal habitats throughout the Bay-Delta estuary. In many cases, these species are exotic species introduced through boat hulls, ballast water, and intentional introductions for commercial and recreational use. The Asian clam (*Corbula amurensis*) was introduced into the northern Bay in the 1980s and, through an explosive increase in population, replaced the resident clams and began filtering enough algae from the water column to significantly reduce the food available to other species (Carlton et. al. 1990).

Exotic crab species, the green crab and Chinese mitten crab, contribute to erosion and loss of marsh habitat through burrowing in tidal channels. In addition, smooth cordgrass (*Spartina alterniflora*) can outcompete native cordgrass, altering vegetative structure and habitat for endangered species, such as the California clapper rail. The spread of smooth cordgrass to tidal flats may inhibit the exchange of sediment from tidal flats to tidal marshes, preventing migration and impacting migratory bird populations.

While the impacts of climate change may aid or deter a particular invasive species, the shifting of the ecosystem away from the conditions under which native species evolved will aid invaders who can better adapt to the changed conditions. For example, warmer conditions will make the Bay more hospitable to invasive species from the south.

Threat of Extinction

The Bay ecosystem supports a diverse range of threatened and endangered species. Climate change impacts, such as warmer water temperatures and reductions in the amount of tidal marsh, are likely to make it harder to recover threatened and endangered species and may cause more species to become threatened and endangered.

The plummeting populations of several species of Delta and North Bay fishes during the early 2000s is referred to as the pelagic (open water) organism decline (POD). The abundance indices for 2002-2004 include record lows for the Delta smelt and young striped bass and near-record lows for threatened longfin smelt and threadfin shad. The POD has been attributed to a combination of factors: toxins, such as pesticides and herbicides; invasive species, such as the such as the overbite clam, which consumes plankton and other food needed by small fish; and the huge pumps used for state and federal water project operations, which entrain small fish and impact salinity and circulation patterns in the estuary.

The Delta smelt is listed as threatened by the U.S. Fish and Wildlife Service and as endangered by the California Department of Fish and Game. Warmer estuarine waters resulting from climate change will further increase the risk of extinction for this and other fish species dependent upon cold water. Water temperatures beyond 25 degrees Celsius are lethal to Delta smelt, a threshold that is already reached in the estuary during summer heat waves.

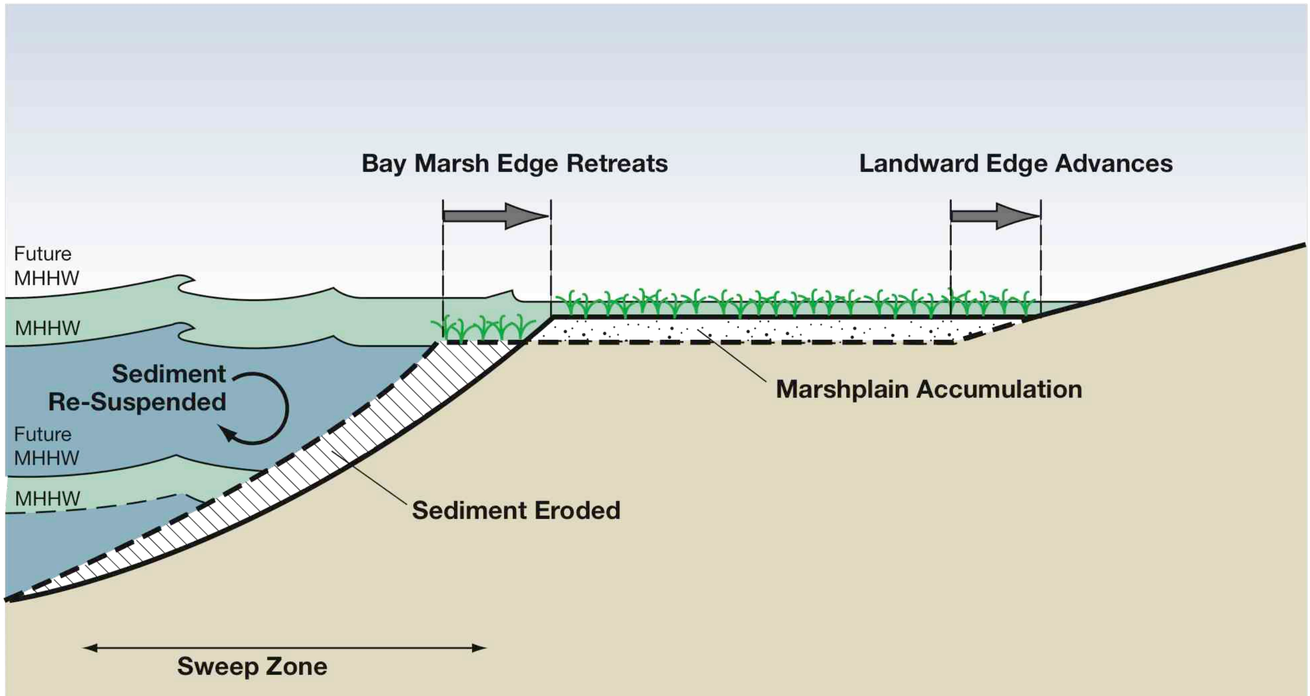
The endangered California clapper rail seeks refuge in high tidal marshes during extreme high water events. Sea level rise and declining sediment supply threaten high marsh and upland transition zones that act as refugia for the clapper rail, posing a significant challenge to providing adequate habitat to enable the recovery of this species.

Tidal marshes and tidal flats are important habitat for a number of bird species migrating along the Pacific Flyway. For many birds who rely on tidal marshes and flats, the loss of breeding habitat results in smaller populations. As tidal habitats are lost or degraded, some birds may move to other less suitable habitats, but reproduction in degraded habitats tends to be lower and mortality tends to be higher. The birds that breed in these poorer quality habitats may eventually become threatened or endangered (Pulliam and Danielson, 1991).

Although resource managers are shifting their emphasis from single-species management to an ecosystem-based management approach, preventing extinction remains an important goal and is required by the state and federal endangered species acts. In addition, monitoring the abundance of threatened and endangered species, particularly those that provide early warning of climate change, is critical to ensuring the health of the Bay ecosystem.

Figure 3.1 Estuary Migration

Source: Lowe and Williams, 2008



Shoreline Protection Impacts

Static structures have been constructed on tidal marshes and tidal flats, a practice that restricts migration of the Bay ecosystem landward during sea-level rise. Shorelines move upward and landward with sea level rise, forming tidal marshes and tidal flats further inland. As sea level rises, high-energy waves erode mud from tidal flats and deposit that sediment onto adjacent tidal marshes (Figure 3.1). Plants establish on tidal marshes trapping additional sediment and accumulating organic material. If sedimentation and organic accumulation in tidal marshes is sufficient, tidal wetlands persist on the Bay shoreline in the same relative position, rising at the same rate as sea level (PWA and Faber 2004, Watson 2004). If sedimentation is slower than sea level rise, tidal marshes and tidal flats begin to erode and the area in front of shoreline protection structures converts to open water (PWA and Faber, 2004, Lowe and Williams 2008).

Because tidal marshes and tidal flats decrease wave heights or attenuate waves, the loss of tidal marsh seaward of protection structures further exacerbates potential flooding and erosion during storms by allowing larger waves to reach the structures. Studies in the United Kingdom

(Möller 2001, 2002, 2006) estimate that salt marshes in front of levees reduce wave heights by as much as 40 percent, reducing required levee height and lowering the total cost of the levee by 30 percent (Turner and Dagley 1993). Seawalls, in particular, create a hard, smooth surface that reflects wave energy back onto the shoreline, eroding and undermining the base of the structure and leading to failure (BCDC 1988a). Riprap revetments dissipate this energy somewhat, but are also vulnerable to erosion at the base of the structure and at each end (BCDC 1988a). Sea level rise requires that engineers retrofit existing structures to protect against larger waves, usually by raising the height of the structure and by strengthening the seaward base (Lowe and Williams 2008, Smits et. al. 2006, Heberger et. al. 2008).

Ecological Consequences of a Tidal Barrage. In 2007, BCDC reported on the potential impacts on San Francisco Bay from a tidal "barrage" across the Golden Gate (barrage is the technical term for a barrier or dam across a waterway). It is foreseeable that such a structure could be proposed as an alternative to the extensive shoreline protection structures that may be built in response to sea level rise. After the North Sea flood in 1953, the Dutch sacrificed entire estuaries to build similar structures. The results of BCDC's study indicate that constructing a barrage at the mouth of San Francisco Bay would likely be physically and economically impractical, as well as ecologically damaging. The ecological consequences of the barrage would likely be very high. It would affect sedimentation, wetlands, fresh and salt water mixing, animal migration, and endangered species. More than likely it would change the landscape of the Bay Area, affecting the North Bay and South Bay most heavily.

Damming the Bay would result in less salt water entering the Bay and more fresh water being trapped within. Overall the Bay would become more brackish and less saline. Exchange of nutrients and plankton between the ocean and Bay would also be greatly reduced. There would be reduced ability to assimilate wastewater discharges, resulting in reduced water quality and the need for expensive modifications to wastewater treatment facilities.

A barrage would likely greatly decrease sediment exchange between the Bay and the ocean. The reduced sediment load has the potential to increase coastal erosion. Currently scientists and planners are examining whether the existing wetlands will be able to keep pace with sea level rise. As sea level rises in the ocean, a barrage would decrease tidal range in the Bay, eliminating many intertidal areas by converting them to subtidal areas, further decreasing Bay tidal flats and wetlands.

Fish and marine mammals are likely to be the most affected as migratory pathways would be greatly reduced, and species using the Bay as a nursery ground, such as Dungeness crab and many species of flat fish, would be blocked. Changing the salinity regime would also eliminate species that require higher salinities from the Bay. Birds that are dependent on marine fish for food and shorebirds that depend on the mud flats would likely have to relocate. Science has shown that the Bay is one of the most important stops of the Pacific flyway, altering this habitat would have global effects on birds that stop here on their yearly migration.

The Bay is home to numerous threatened and endangered species such as Chinook salmon, steelhead and green sturgeon. Sturgeon have been known to go through lock systems but only on an accidental basis. Placing fish gates and ladders in the barrage would alleviate some of the issues, but creating obstacles for already stressed and endangered species only pushes them further towards extinction. Reducing fish populations would also affect endangered least terns and brown pelicans, reducing their chances for survival.

While creating a barrier to sea level rise may seem to solve flooding issues due to storm surges and rising ocean waters, it may exacerbate flooding inside the Bay during heavy winter storms. Reducing the ability of fresh water to be released into the ocean would cause severe flooding if excess water has no place to go. Should long term sea level rise exceed 6.56 feet (2 meters), then tidal flows would no longer be possible and outflow from tributaries would require pumping through the barrage.

Watershed Land Use

Watershed management must account for the need for sediment to feed the marshes and mudflats, while not hampering pollution control or increasing sediment impacts to creeks that require clean gravels for spawning salmon and steelhead trout.

Inflowing waters and sediments from local tributary watersheds of the San Francisco Bay are increasingly recognized as important components of a healthy Bay ecosystem (Collins and Grossinger 2004). Tributaries of the Bay contribute freshwater and sediment that help sustain the tidal marshes and tidal flats where rivers meet the Bay (Collins and Grossinger 2004, Grossinger et. al. 2007). Approximately 10 percent of the tidal flats in the Bay and Delta are in the tidally influenced portions of major tributaries of the Bay.

However, natural flows of water and sediment from watershed to the Bay have been altered by development. Urbanization in Bay area watersheds has led to increases in paved, impermeable surfaces, construction of storm drains, and culverting and channelization of creeks. As a result, during storms, rain that is unable to soak into the ground flows over paved surfaces, washing accumulated pollutants into storm drains, creeks and, eventually, the Bay. Faster, more concentrated stormflows enter creeks, increasing channel erosion and bank undercutting, which degrades fish habitat and undermines bridges, buildings and trails located along creeks. In some areas, flooding has become more severe.

Over ten years of research for the Regional Monitoring Project (RMP) has shown that sediment is the main transport mechanism for pollutants entering the Bay (Schoellhammer 2007, Flagel and Davis 2007).. Total Maximum Daily Loads (TMDLs) limiting suspended sediment in creeks under the Clean Water Act have established a regulatory mechanism for reducing pollutant loads into the Bay and protecting salmon and steelhead spawning habitat. Localities have begun implementing best management practices such as floodplain setbacks and easements, infiltration basins, and creek and riparian habitat restoration, and in order to accommodate flood flows and limit sediment and pollutant loads to creeks and the Bay.

However, given the decrease in sediment supply and loss of tidal flats, fine sediment supply from watersheds could be critical for maintaining equilibrium in tidal marshes, particularly in light of sea level rise. The challenge for future watershed management strategies will be to enable sufficient amounts of clean sediment to pass through watersheds to the Bay, while avoiding adverse impacts to fish and water quality (Box 3.1).

Restoration and Adaptive Management

Managing the health of the Bay requires a regional process to establish goals for the protection and restoration of wetlands or baylands, ensuring the cumulative success of individual efforts. The Baylands Ecosystem Habitat Goals report (Goals), released in 1999, represents a consensus among area scientists and resource managers. It serves as a guide for sustaining diverse and healthy communities of fish and wildlife resources in the San Francisco Bay Estuary by providing recommendations for the necessary kinds, amounts, and distribution of baylands and related habitats. The Goals provide a flexible vision for restoration that translates into tangible actions.

In the decade since its release, over 75 projects have been initiated to restore baylands along the fringes of San Pablo Bay, South Bay, Suisun Marsh, and throughout the Sacramento-San Joaquin Delta. These projects range in size from just a few acres to some 15,000 acres (23 square miles) of salt ponds in the South Bay. Roughly 67,000 acres (104 square miles) have been restored to natural areas or are planned for restoration (Wetland Tracker 2008). These projects represent a tremendous public investment in preserving the baylands for future generations; however, the impacts of climate change may jeopardize that investment if the Goals are not updated to account for climate change.

Climate change impacts require revision of the Goals to ensure that we maintain and expand the invaluable resources that the baylands provide. Within the next 10 to 50 years, the Baylands will face more flooding of potentially greater magnitude that could erode or degrade water quality and existing wildlife habitat in irreparable ways. While restoring historic habitat conditions may not be feasible, restoring ecosystem function is essential for enable habitats to adapt to the new stressors and challenges resulting from climate change. The best available science must be used to strategically select restoration sites that are likely to continue to provide ecological services as they evolve in response to sea level rise and other climate change impacts.

Box 3.1 Shoreline Management and Watershed Management Planning

Shoreline Management. Shoreline management plans generally address erosion and flooding hazards in coastal areas. They are widely used in the United Kingdom and the European Union to plan for the effects of sea level rise. Shoreline management planning involves dividing the shoreline into a series of natural units or drift cells within the shoreline planning area and developing a management plan for each cell. The shoreline management plans further divide the cells by land use and develop strategies for the following 50-100 years, such as: holding the line, managed realignment (similar to managed retreat), or no intervention. In the UK, the Department of Environment Flood and Rural Affairs developed guidelines with which strategies must be consistent. Implementing the strategies is left to the local authorities. Shoreline management plans are designed to be regularly updated to effectively adapt to changing circumstance and new scientific information as the climate conditions change (DEFRA 2007).

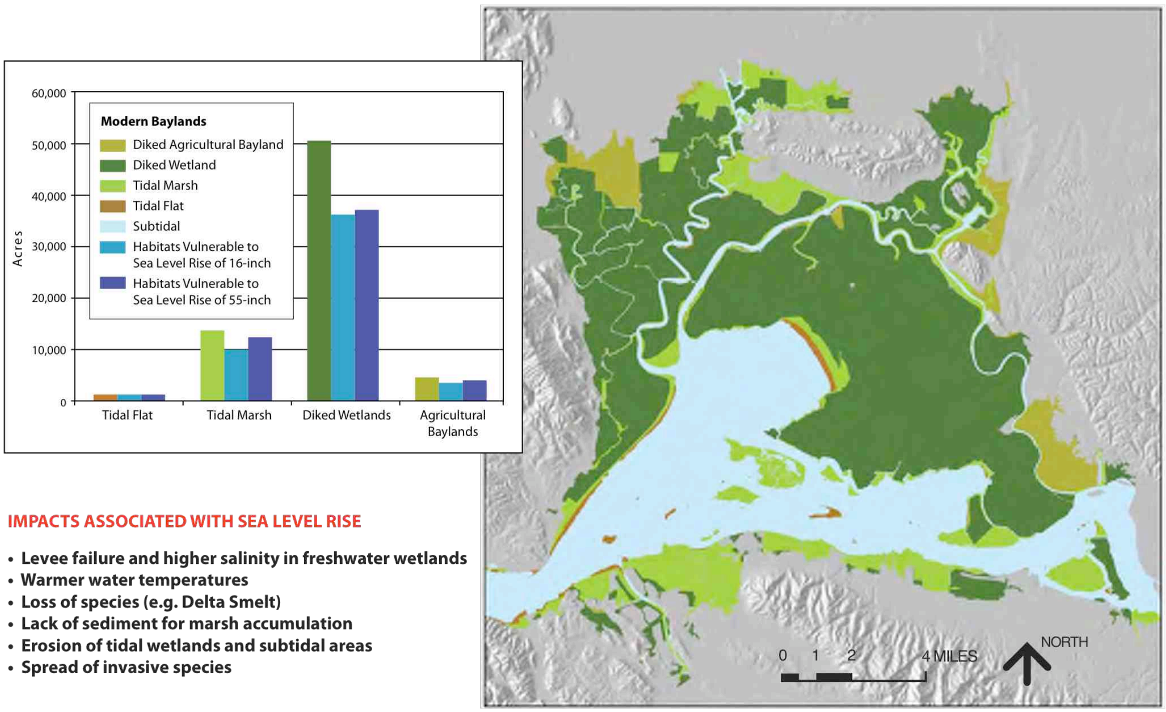
The advantages of shoreline management plans are similar to watershed management plans where they avoid a piecemeal approach by setting clear guidelines for a specific planning area that is determined based on ecosystem processes, such as littoral drift cells or a watershed. This is especially effective for managing shoreline erosion because the each individual hard shoreline structure that is approved can cause erosion on adjacent properties and eliminate potential marsh migration areas.

Watershed Management. Integrated watershed management is a planning concept developed to reconcile competing uses that degrade watersheds. It aims to meet multiple objectives across large spatial scales by coordinating the actions of numerous communities and sectors (MEAM 2008). Some primary goals of integrated watershed management are to provide adequate freshwater flow for ecosystem and human needs, maintain healthy riparian habitat and water quality, and mitigate past and future watershed impacts.

There are many examples of watershed (or catchment) management frameworks and programs around the world. Locally-based programs, such as the California Coastal Commission's Critical Coastal Area program (http://www.coastal.ca.gov/nps/cca-nps.html), aim to track and minimize contaminants and development pressures throughout an entire watershed, e.g., Sonoma Creek, upstream of San Francisco Bay. Other examples, such as the Bay Area Integrated Water Management Plan (IRWMP), aim to develop regional cooperation between many resource agencies and local stakeholders, in many cases resulting in a watershed management plan. Watershed management plans reflect a set of common goals that meet the needs of the watershed community, including humans and ecosystems.

Figure 3.4 Suisun Marsh Habitats Vulnerable to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)

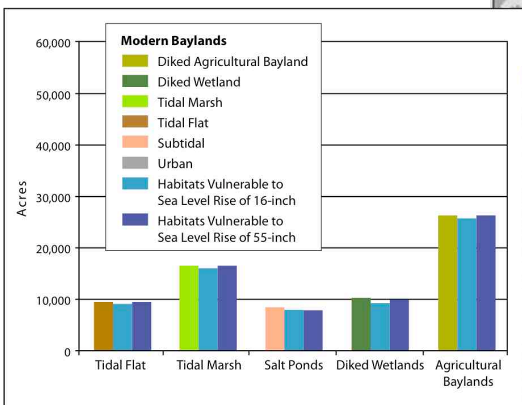


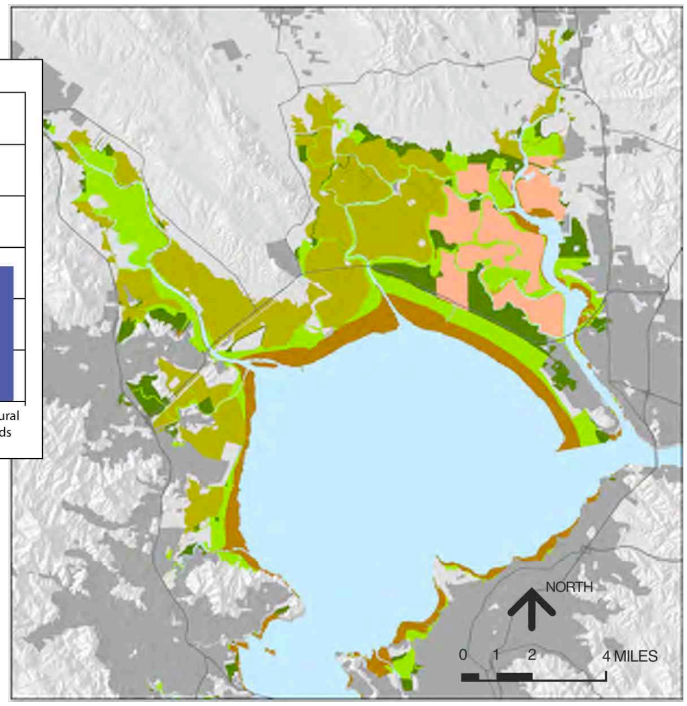
Suisun Marsh (Figure 3.4). The Suisun Marsh Charter Group formed in 2001 to develop a new restoration and management plan for the Marsh. The first phase of the Suisun Marsh Plan will involve converting between 2,000 and 9,000 acres (3 and 14 square miles) of managed wetlands to tidal marsh and enhancing between 39,000 and 46,000 acres (60 and 72 square miles) of managed wetlands to benefit a variety of species.

Tidal restoration objectives include restoring tidal marshes contiguous with upland transitions; expanding the distribution and amount of sloughs and shallow subtidal habitat; restoring natural processes, increasing productivity and nutrient export to adjacent Bay waters; and enhancing populations of listed and sensitive native species (Wilcox 2006). Constraints to tidal restoration include subsidence, limited sediment supply, protecting infrastructure, effects on salinity, protection of neighboring properties and reduction of managed marsh. Since most of the managed wetlands in the Marsh are at or below sea level and sediment supply is limited, breaching levees would create shallow water habitat rather than tidal wetlands in many areas.

Figure 3.5 North Bay Marsh Habitats Vulnerable to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)





IMPACTS ASSOCIATED WITH SEA LEVEL RISE

- **Lack of sediment for marsh accumulation**
- **Erosion of tidal wetlands and subtidal areas**
- **Loss of species (e.g. CA Clapper Rail)**
- **Spread of invasive species**
- **Salinity change in Bay tributaries**

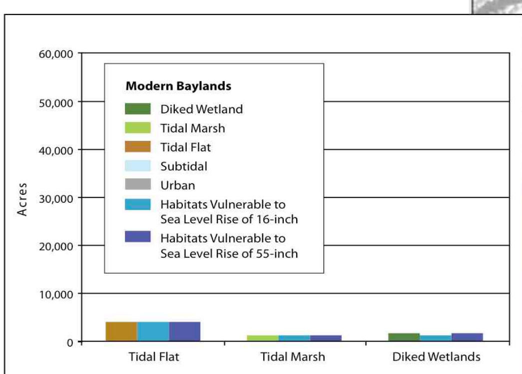
Tidal restoration opportunities will be constrained by their salinity effects on other parts of the Delta, particularly those areas where water is withdrawn for export by the state and federal water projects. Levee failure in diked wetlands would increase salinity variability by returning them to tidal action if the levees were not repaired. If a major earthquake or flood were to cause catastrophic levee failure and the flooding of several Delta islands, the tidal prism would increase dramatically, resulting in increased salinity in the Bay and Suisun Marsh, as well as changes in erosional and depositional patterns in the estuary (Healey 2008). The Suisun Marsh Plan will have to consider the potential salinity impacts of sea level rise, climate-induced changes in the hydrological regime of the Bay-Delta Watershed, and proposed changes in storage and conveyance by the state and federal water projects.

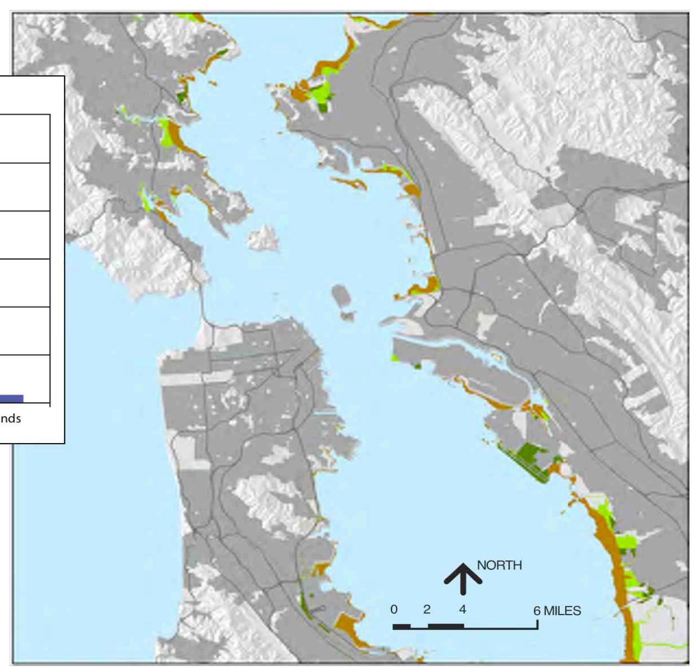
Sea level rise will make managed wetlands increasingly difficult to maintain. Higher water levels will put more pressure on fragile levees, increasing the risk of failure. Sea level rise will also reduce managers' ability to use gravity to periodically drain the wetlands in order to flush out salts and manage vegetation by discing and planting.

North Bay (Figure 3.5). Most of the North Bay supports a mix of diked agricultural baylands, managed wetlands, and tidal marsh. The Petaluma and Napa Rivers and Sonoma and Tolay Creeks also flow into the North Bay, supporting large areas of brackish marsh. Currently, approximately 14,000 acres (22 square miles) of baylands are restored or are in the process of being restored to tidal habitat in the North Bay. An additional 10,000 acres (15 square miles) are planned for tidal habitat restoration, despite recent erosion of the tidal flats in the North Bay. Tidal flats in the North Bay are replenished increasingly by sediment from local tributaries such as the Napa River and Sonoma Creek. These local tributary watersheds are sufficiently large to supply adequate amounts of sediment. However, current watershed management practices, such as damming, are reducing sediment throughput to the Bay, leading to erosion of the tidal flats and marshes.

Figure 3.6 Central Bay Habitats Vulnerable to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)





IMPACTS ASSOCIATED WITH SEA LEVEL RISE

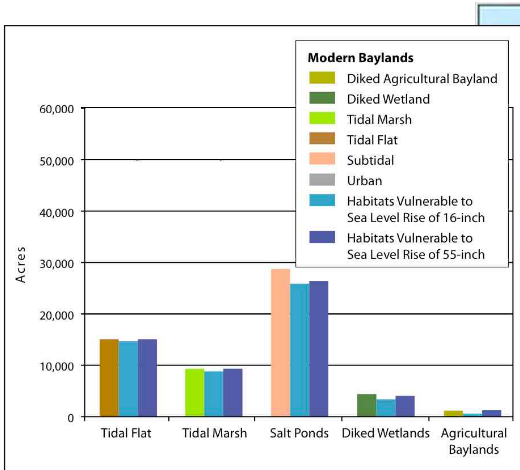
- **Levee failure and flooding of urban areas**
- **Erosion of subtidal areas**
- **Ocean acidification and water quality impacts**
- **Spread of invasive species**

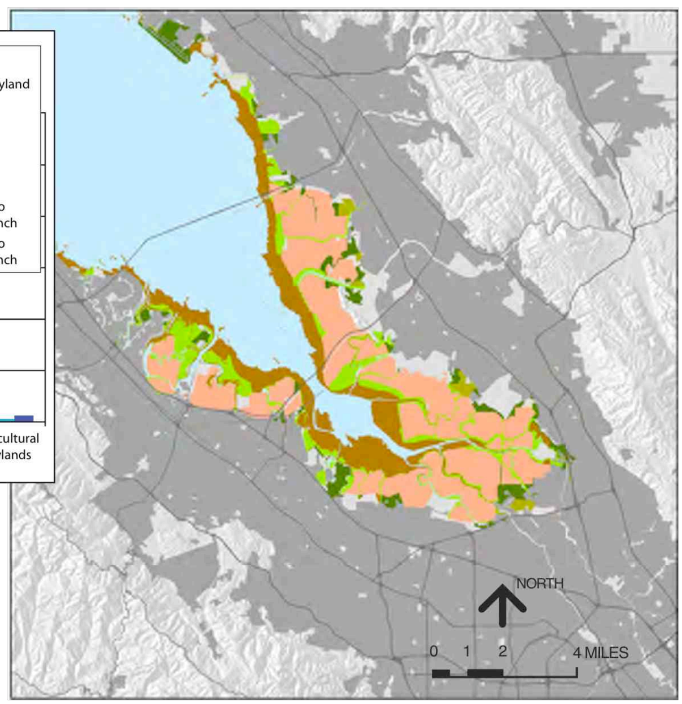
Central Bay (Figure 3.6). Subtidal areas are the dominant habitat in the Central Bay, which includes the Golden Gate, San Francisco and Oakland shorelines. It is the deepest part of the Bay and, thus, the central shipping corridor. Most of the shoreline is developed with riprap revetments or bulkheads. However, the largest eelgrass beds in the Bay are located here.

The Subtidal Habitat Goals Project is a collaborative interagency effort between BCDC, the California Coastal Conservancy, National Oceanic and Atmospheric Administration (NOAA), and the San Francisco Estuary Project. The Subtidal Goals Project will establish a comprehensive and long-term vision that accounts for the impacts of climate change for research, restoration and management of the subtidal habitats of the San Francisco Bay. Resource managers will be able to use the resulting document to make informed decisions, and researchers will be able to prioritize activities and pursue funding for subtidal projects.

Figure 3.7 South Bay Marsh Habitats Vulnerable to Sea Level Rise

SOURCE: Baylands (EcoAtlas 2009), Hillshade (USGS NED)





IMPACTS ASSOCIATED WITH SEA LEVEL RISE

- **Lack of sediment for marsh accumulation**
- **Erosion of tidal wetlands and subtidal areas**
- **Loss of species (e.g. CA Clapper Rail)**
- **Spread of invasive species**
- **Salinity change in Bay tributaries**
- **Algal blooms in shallow ponds**

South Bay (Figure 3.7). The South Bay is the focus of the largest tidal restoration project ever planned for the Pacific Coast, the South Bay Salt Ponds (SBSP) restoration project. Preliminary design for the SBSP project involves restoration of 15,000 acres (23 square miles) to a mixture of tidal flat, tidal marsh, and transitional habitat. The project's goals are to restore and enhance wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation. The project seeks a balance between restoring wetland habitat and maintaining existing pond habitat, with alternative scenarios ranging from 50 percent each of wetlands and ponds to 90 percent wetlands and 10 percent ponds. The project participants identified eight key uncertainties that could make meeting the project objectives difficult. These included sediment dynamics, bird response to changing habitats, non-avian species responses, mercury issues, invasive and non-native species, water quality, public access and wildlife, and social dynamics. The overarching uncertainty of global climate change is incorporated into each of the specific key uncertainties.

Initial investigation of the impacts of sea level rise on the SBSP project suggest that sufficient sediment exists to raise subsided sites to elevations suitable for plant growth. However, long term replenishment of the tidal flats, a critical source of sediment, may be in jeopardy if resource managers do not successfully manage sediment in the South Bay. Potential adaptive management actions to address sediment supply include: incorporating monitored changes in sediment supply and mudflat distribution into project phasing; using low-crested levees along the bayfront edge to reduce wave energy, protect restored tidal areas, and encourage marsh sedimentation; reconnecting existing mudflats to salt ponds to allow for natural sedimentation; using dredged material to raise pond elevations to a level conducive for growth of vegetation, augmenting natural sedimentation; and prioritizing restoration in ponds adjacent to intertidal mudflats and/or ponds at higher elevations which will require less dredged material and natural sediment supply to offset migration from sea-level rise.

Table 3.1 Summary of Vulnerabilities in the Bay Ecosystem

Bay Ecosystem Subregions	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	**Adaptive Capacity**	**Vulnerability**
Suisun Marsh	Subsided wetlands that rely on freshwater inflow imported through salinity gates. Older levees constructed on peat.	Potential flooding from levee failure. Change in Salinity. Loss of species. Lack of sediment. Erosion and invasive species.	High – Subsidence and older levees make the Marsh very sensitive to flooding. Salinity changes can significantly alter habitats.	Low/Medium – Without levee improvements and rethinking management strategies, the Marsh will suffer. Marsh has space to migrate upland.	High
North Bay	Tidal flats are eroding, reducing sediment supply to marshes. Brackish marsh has high biodiversity, but requires freshwater inflow.	Increased erosion and lack of sediment for restoration. Invasive species and loss of biodiversity. Salinity changes near and in tributaries.	High – Managed wetlands are especially susceptible to erosion. Brackish marsh is relatively unique habitat in the Bay..	Medium – Current rates of erosion and lack of sediment may hamper marsh restoration efforts and upland migration. Plentiful open space is available for upland migration.	Medium High
Central Bay	Intense human activity, including shipping, dredging, mining and industrial uses that threaten eel grass beds and impact water quality.	Erosion of subtidal areas. Acidification and other water quality impacts. Spread of invasive species. Major structural shoreline protection to protect urban shoreline can increase erosion.	Medium – Unique subtidal habitats, like eel grass beds, are difficult to restore and their limited numbers could result in total loss.	Medium Low - Eel grass beds may not be adaptable. A great deal of uncertainty remains regarding the affects of acidification and salinity. Little space for marsh migration.	Medium
South Bay	Major restoration efforts will require sufficient amounts of sediment for success. Levees surrounding salt ponds are older and may require improvements.	Lack of sediment for marsh accumulation and increased erosion. Spread of invasive species. Algal blooms in shallow ponds.	High - Current restoration efforts require adequate sediment to succeed.	Low - Although restoration will improve ecosystem functions, little space is available for marsh migration.	High

Summary and Conclusions

The Bay is inhabited by numerous plants and animals and provides many benefits to humans. For example, tidal wetlands provide critical flood protection, improve water quality, and sequester carbon. Brackish marshes in the North Bay and Suisun Marsh support the greatest diversity of species and provide an important resting place along the Pacific Flyway. The impacts of climate change will substantially alter the Bay ecosystem by inundating or eroding wetlands and transitional habitats, altering species composition, changing freshwater inflow, and impairing water quality. Changes in salinity from reduced freshwater inflow affect fish, wildlife and other aquatic organisms in intertidal and subtidal habitats. The highly developed shoreline combined with reduced freshwater inflow constrains the natural adaptation mechanism of tidal marshes—to migrate upland—by reducing sediment and occupying open space to which marshes could otherwise migrate. The vulnerabilities from future climate change are further summarized in Table 3.1.

The Bay will continue to evolve in response to the climatic forces that enabled it to come into being. Historic modification of the ecosystem, through filling, diking, and building on the shoreline and reducing freshwater inflow, as well as ongoing stressors such as pollution and invasive species, have resulted in the decline of many native species and increased the vulnerability of surrounding communities to damaging floods. Substantial progress has been made in restoring the Bay ecosystem by returning diked areas to tidal action and reducing pollution, while efforts to increase freshwater inflow have been less successful. Future efforts to restore the Bay ecosystem can benefit from careful design that accounts for the known processes affecting formation of habitats in the Bay, the constraints imposed by existing stressors, and the future vulnerabilities.

Key issues that resource managers must address regarding climate change include: identifying opportunities for tidal wetlands and tidal flats to migrate landward, managing and maintaining adequate volumes of sediment for marsh sedimentation, developing and planning for natural flood protection, and maintaining sufficient upland buffer areas around tidal wetlands. Furthermore, habitats, like beaches, should be high priority for restoration and conservation.

Developing effective strategies to protect tidal wetland and tidal flat from sea level rise is extremely challenging because the projections of future sea level rise continually change. Since the 1980's, when widespread scientific concern about climate change and sea level rise emerged, projections for sea level rise have varied widely. This range of variation, based on different climate models and emission scenarios, creates a great deal of uncertainty for decision-makers, and therefore, wetland protection strategies must be adaptable to changing conditions.

CHAPTER 4
GOVERNANCE: WHAT BCDC AND LOCAL JURISDICTIONS CAN DO

The vulnerabilities of the Bay shoreline and ecosystems to sea level rise and other climate change impacts will create new technical challenges for shoreline planning, and require difficult decisions to prioritize protection of shoreline development and Bay resources. This chapter assesses the vulnerabilities in Bay Area governance systems that may hinder the region's ability to meet these challenges. The analysis begins by identifying vulnerabilities in the overall organization of government agencies and their authorities, and then focuses on BCDC and local governments because of their central roles in adapting to the impacts of climate change on the Bay and its shoreline.

BCDC is addressing regional adaptation for a variety of reasons. The Commission has authority over San Francisco Bay and shoreline from just outside of the Golden Gate Bridge to the Delta, and its laws and policies establish the agency's responsibility for protecting and enhancing the Bay, and encouraging the Bay's responsible use. As one of California's federally-designated state coastal management agencies, BCDC has access to state and federal resources to support coastal management. The Commission also has an integral regional role in planning for the Bay through its participation in the Joint Policy Committee, and its partnerships with other regional and local agencies and organizations.

This chapter also lays out the needs of local jurisdictions to effectively address the challenges climate change will pose to their communities. Understanding these needs is essential because local governments have broad land use authority and thus a clear responsibility to adapt to climate change.

The Governance Landscape

BCDC's regional authority and local governments' land use authority give these agencies primary roles in adapting to sea level rise impacts, but they are just some of the many government agencies that are relevant to adaptation planning in the Bay Area. Management authority over Bay and shoreline resources is sliced up among numerous other government agencies as well. Provision of services such as flood control and water supply and quality is managed by different local, regional, state, and federal agencies based on authorities granted to them through various federal, state, and local laws and policies. These sectoral management activities intersect geographic boundaries of agency jurisdiction and land ownership that define the Bay region's parks, wildlife areas, residential communities and industrial and commercial areas. Together, these divisions create a patchwork of jurisdictions and authorities that challenges the region's ability to respond to broad geographic and cross-sectoral impacts such as those expected with a changing climate. In the Bay Area, a number of multi-jurisdictional planning programs have successfully addressed complex environmental issues and, too often, we have failed to follow through. Examples of successful follow-through include the Long Term Management Strategy's Dredged Materials Management Office and permit streamlining, the South Bay Salt Pond Restoration Project, and hazard mitigation planning.

These challenges are not all unique to adaptation planning. Other, regional and sub-regional planning efforts such as the South Bay Salt Ponds Restoration Project and the Multi-Jurisdictional Local Hazard Mitigation Plan, an effort led by the Association of Bay Area Governments (ABAG) (Box 4.1) have faced similar cross-jurisdictional and sectoral issues. These efforts have relied on inter-agency partnerships and extensive outreach to key stakeholders and the public to effectively integrate and address the diversity of authorities and interests relevant to these projects.

However, despite many similarities to past planning efforts, adaptation planning involves additional complexities that government agencies have not previously had to address. Whereas past regional planning efforts have been able to assume a (basically) static environment, or "backdrop" for the planning project, the entire impetus of adaptation planning is a changing environment. Added to this changing backdrop are complexities that are uncommon to other planning projects: climate change impacts are long lasting, but create environmental changes that are relatively rapid compared to historic change; expected intensities of impacts are well beyond the range of historic effects; uncertainty about expected impacts is very high; and there is dearth of experience in rapidly assessing the efficacy of adaptation actions. These complexities magnify the importance of conducting comprehensive regional planning for adaptation, yet exacerbate the challenges associated with this type of planning. These challenges present yet another situation where too many authorities can make it difficult to be flexible in planning for and responding to these complex and relatively rapid changes. Some balance of redundancy and flexibility is required.

Box 4.1 Hazard Mitigation Planning in the Bay Area

Effective adaptation planning is limited by the number of and divisions among management authorities in the Bay Area. These existing governance challenges that will be exacerbated by climate change impacts. Agencies have had to address overlapping jurisdictions and authorities in other Bay Area regional planning efforts. Preparation of the Multi-Jurisdictional Local Hazard Mitigation Plan (Plan) for the Bay Area is one example of this.

Development of the Plan was a "joint effort by the cities, counties, and special districts in the Bay Area to build a more disaster-resistant region," and to meet requirements of the federal Disaster Mitigation Act (DMA) of 2000 for all local governments to develop and adopt this type of plan. The Association of Bay Area Governments (ABAG) coordinated this multi-jurisdicational planning effort to identify hazards to communities, assess risks, and develop a disaster resistance goal and objectives, and a comprehensive list of strategies (or actions) to mitigate the identified risks. ABAG conducted numerous workshops with local governments to determine the scope of work, identify key hazards and develop mitigation strategies for eight different planning, or "commitment," areas. Once the overall Plan for the Bay Area was completed, each city, county and special district prepared an "annex" to the Plan with a more specific assessment of hazards and risks within its jurisdiction, and prioritization and application of mitigation strategies. (For the 2005 Plan, more than 90 local governments prepared annexes.)

In the Plan, ABAG highlights two important characteristics of hazard mitigation that are also true of adaptation planning. First, it recognizes that "disasters do not respect the boundaries between … individual jurisdictions," and that hazard mitigation requires coordinated, cross-jurisdictional planning. Second, it recognizes that hazard mitigation planning is iterative and that the Plan needs periodic updates.

This example of a regionally-coordinated, multi-jurisdictional planning effort offers possible lessons for adaptation planning. The DMA has clear financial incentives for local governments to participate in hazard mitigation planning in the form of disaster recovery grants that become available to municipalities that have plans in place. Assessing vulnerabilities to hazards such as floods, fire and earthquakes requires extensive geographic data analysis. Instead of each local government conducting a separate data collection and mapping effort, ABAG compiled available data and created interactive, web-based mapping tools that allowed each jurisdiction to assess its vulnerabilities within the different commitment areas. This ensured consistency of the analysis across the many jurisdictions, and minimized the workload for local governments.

This planning effort is an opportunity in and of itself for improving the region's adaptive capacity to climate change impacts. As the Plan is updated, the hazard mitigation strategies can be expanded (as appropriate) to address relevant climate change impacts such as sea level rise. Taking advantage of opportunities to integrate adaptation planning into this existing effort could reduce the amount of additional work that climate change will create for local and regional planners.

In the Bay Area, five federal agencies are actively involved in shoreline adaptation: the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the United States Army Corps of Engineers (Corps), and the Environmental Protection Agency (EPA). As one example of federal involvement, the Corps is conducting a shoreline study in the South Bay to identify levee heights and conditions and project wave runup. The state has numerous agencies that are actively addressing climate change adaptation. To date, BCDC has worked primarily with three of the agencies that have been instrumental in funding and managing important research projects related to sea level rise in San Francisco Bay: the California Energy Commission's Public Interest in Energy Research program, the California Coastal Conservancy, and, more recently, the Ocean Protection Council. BCDC also works with the regional agencies on the Joint Policy Committee to carry out the JPC's climate change strategies. Several nearby regional agencies are taking an active role in climate change: the Delta Protection Authority, the Delta Blue Ribbon Task Force, and the Suisun Marsh Resource Conservation District. The Commission provides a staff member to coordinate with these regional efforts.

The Commission's Jurisdiction and Authority

The Commission was established in 1965 as the nation's first state coastal management agency. Alarmed by the fact that between 1850 and 1960 an average of four square miles of the Bay was filled each year, citizens in the Bay Area successfully organized to advocate for new state legislation that would protect the Bay. The McAteer-Petris Act was passed in 1965 to establish BCDC as a temporary state agency. The Commission was charged with preparing a plan for the long-term use of the Bay and regulating development in and around the Bay while the plan was being prepared.

The *San Francisco Bay Plan* (Bay Plan), which was completed in January 1969, includes policies to protect the Bay as a resource and policies to guide development of the shoreline, ranging from ports and public access to water quality and habitat. The Bay Plan also contains maps of the entire Bay that designate shoreline areas that should be reserved for water-related purposes like ports, industry, waterfront parks, airports, and wildlife refuges. The Commission is directed to pursue an active planning program to study Bay issues so that Commission plans and policies are based upon the best available current information.

In August 1969, the McAteer-Petris Act was amended to make BCDC a permanent agency and to incorporate the policies of the Bay Plan into state law. In 1977, the Suisun Marsh Presrvation Act expanded the Commission's authority to provide special protection of the Suisun Marsh. The Suisun Marsh Protection Plan includes policies that guide the Commission and local jurisdictions in their review of marsh development permits as well as the Commission's review of local protection plans developed by local jurisdictions within the marsh.

BCDC is the federally-designated state coastal management agency for the San Francisco Bay segment of the California coastal zone. This designation empowers the Commission to use the authority of the federal Coastal Zone Management Act to ensure that federal and federally-permitted or funded activities are consistent with the McAteer-Petris Act and the Suisun Marsh Preservation Act and Protection Plan, BCDC regulations, and the policies of the Bay Plan.

Because the Commission was created in response to rampant filling of the Bay and a dearth of shoreline public access, the primary focus of the Commission's authority is on preventing unnecessary fill in the Bay and improving public access. Although fill is defined very broadly, this focus limits the ability of the Commission to address climate change issues.

The Commission's Jurisdiction. The Commission has jurisdiction over San Francisco Bay, including the Suisun Marsh, certain named waterways, salt ponds, managed wetlands, and a 100-foot shoreline band. Section 66610 of the McAteer-Petris Act describes the area of the Commission's jurisdiction over San Francisco Bay as follows:

> …"all areas that are subject to tidal action from the south end of the Bay to the [mouth of the] Golden Gate (Point Bonita-Point Lobos) and to the Sacramento River line (a line between Stake Point and Simmons Point, extended northeasterly to the mouth of Marshall Cut), including all sloughs and specifically, the marshlands lying between mean high tide and five feet above mean sea level….

The Commission typically refers to the above description as its Bay jurisdiction. Section 66610 also describes the Commission's shoreline band jurisdiction, which includes the land "between the shoreline of San Francisco Bay…[as described above] …and a line 100 feet landward of and parallel with that line." The Commission does not have shoreline band jurisdiction upland and adjacent to certain named waterways, salt ponds or managed wetlands.

In the 1970s, the Commission worked with other agencies and advocacy groups to develop the Suisun Marsh Protection Plan, which was enacted into law with the passage of the Suisun Marsh Preservation Act of 1977. The Act gives the Commission permit authority over an approximately 89,000-acre primary management area. Local jurisdictions retained permit authority over a 22,500-acre secondary management area, pursuant to their local protection programs approved by the Commission.

The Commission's Permit Authority. Section 66632 of the McAteer-Petris Act grants the Commission authority to require permits for projects in "any water, land or structure, within the area of the Commission's jurisdiction" for the following activities: (1) the placement of fill; (2) the extraction of materials; and (3) any substantial change in use of any water, land or structure. It further requires that projects provide "maximum feasible public access."

1. **Fill.** The McAteer-Petris Act broadly defines the term "fill" to include "earth or any other substance or material, including pilings or structures placed on pilings, and structures floating at some or all times and moored for extended periods…." Projects that involve the placement of fill in the Commission's Bay and certain waterway jurisdiction must be consistent with Section 66605 of the McAteer-Petris Act, which requires the Commission to perform a tiered analysis. First, the Commission must determine whether the public benefits of the fill exceed the public detriment. Then, the Commission can approve fill when the fill is for a water-oriented use or when the fill is a minor amount to improve shoreline appearance or public access. Finally, the fill can be approved only when: (a)

there is no alternative upland location for the fill; (b) it is the minimum amount of fill necessary to achieve the purpose of the fill; (c) the nature, location and extent of the fill minimizes harmful effects to the "environment," as defined in the California Environmental Quality Act (CEQA); (d) the fill is constructed with sound safety standards for public health, safety, and welfare; (e) the fill establishes a permanent shoreline; and (f) the applicant has valid title to the property.

Where a shoreline area was constructed on Commission-approved Bay fill, the Commission retains its Bay jurisdiction over that portion of the shoreline. The Commission approves fill for shoreline protection, minor fill to improve shoreline appearance, for a water-oriented use, or to establish a permanent shoreline, provided that the fill satisfies all other provisions of the law.

2. **Extraction of Materials.** The Commission has the authority to require permits for proposals that involve the extraction of materials (e.g. dredging) in the Bay, certain waterways, salt ponds, and managed wetlands. The Bay Plan policies on dredging, in part, require dredging activities to be consistent with the Long Term Management Strategy for dredged materials in San Francisco Bay, establish the interagency Dredge Materials Management Office, encourage the beneficial reuse of dredged materials, and provide specific requirements for approving permits for dredging activities.

3. **Substantial Change in Use.** Government Code Section 10125 defines a substantial change in use in salt ponds and managed wetlands as "any change in use including abandonment…[and] draining…." In other areas within the Commission's jurisdiction a substantial change in use is defined as "construction, reconstruction, alteration, or other activity, whether or not involving a structure…" and includes: a change in the category of use of a structure, in the intensity of use, an adverse affect on public access or future public access, or any subdivision of land pursuant to the Subdivision Map Act.

Salt Ponds and Managed Wetlands. The Commission's evaluation of fill projects in salt ponds and managed wetlands is limited to their consistency with Section 66605 (c) through (g) of the McAteer-Petris Act. The requirement to weigh the public benefits and detriments of the fill does not apply in these portions of the Commission's jurisdictions. Likewise, the test of whether fill could be sited on an alternative upland location is not required. Regarding permit requirements in salt ponds, the "extraction of materials" is limited to materials extracted for activities associated with salt production. Furthermore, the Commission's salt pond jurisdiction extends to dikes and protective structures that form the ponds.

Managed wetlands located in primary and secondary management areas of the Suisun Marsh are subject to additional policies in the Suisun Marsh Protection Plan and the Suisun Marsh Preservation Act of 1977. Those policies address a range of ecosystem and infrastructures issues, such as: water supply and quality, natural gas resources, utilities, transportation, and recreation.

The 100-foot Shoreline Band. Within the Commission's shoreline band jurisdiction the Commission may only deny a permit for a project that: (1) fails to provide maximum feasible public access consistent with the project; or (2) conflicts with the use designated in a priority use area (McAteer-Petris Act Section 66632.4). Despite this limitation, the Commission is granted authority to require permits in the 100-foot shoreline band for all of the reasons described above. However, the Commission can only condition a permit—require changes to the project—to bring the project into compliance with the requirement to provide maximum feasible public access and to be consistent with a priority use.

The Commission evaluates every permit application to ensure that project proposals provide the "maximum feasible public access consistent with the project." The Bay Plan policies on public access guide the Commission's evaluation of public access proposals. Those policies further provide guidance for public access and wildlife compatability, the siting and design of public access areas. The policies also require public access to be permanently guaranteed and maintained.

Priority use areas are for shoreline uses that are important to the region and require a shoreline location. They include, water-related industries, airports, wildlife refuges, and waterfront parks and beaches. Shoreline areas are designated as priority use areas in order to minimize the need to fill the Bay if land is unavailable for those uses.

Existing Bay Plan Policies Pertaining to Sea Level Rise. In 1988, the Commission updated the Bay Plan to address potential impacts from sea level rise, based on the best available information about sea level rise at the time. In 2000, the Commission amended the Bay Plan policies on Tidal Marshes and Tidal Flats. As a result of the 1988 and 2000 policy updates, the Bay Plan was amended to include the following policies:

- **Safety of Fills, Policy 4.** To prevent damage from flooding, structures on fill or near the shoreline should have adequate flood protection including consideration of future relative sea level rise as determined by competent engineers. As a general rule, structures on fill or near the shoreline should be above the wave run-up level or sufficiently set back from the edge of the shoreline so that the structure is not subject to dynamic wave energy. In all cases, the bottom floor level of structures should be above the highest estimated tide elevation. Exceptions to the general height rule may be made for developments specifically designed to tolerate periodic flooding.

- **Safety of Fills, Policy 6**. Local governments and special districts with responsibilities for flood protection should assure that their requirements and criteria reflect future relative sea level rise and should assure that new structures and uses attracting people are not approved in flood prone areas or in areas that will become flood prone in the future, and that structures and uses that are approvable will be built at stable elevations to assure long-term protection from flood hazards.
- **Tidal Marshes and Tidal Flats, Policy 5**. This policy provides specific requirements for the design and evaluation of tidal marsh restoration projects, which includes an analysis of the following: (a) the effects of relative sea level rise; (b) the impact of the project on the Bay's sediment budget; (c) localized sediment erosion and accretion; (d) the role of tidal flows: (e) potential invasive species introduction, spread, and their control; (f) rates of colonization by vegetation; (g) the expected use of the site by fish, other aquatic organisms and wildlife; and (h) site characterization.

Except in the case where a structure is proposed on Bay fill, the policies on safety of fills largely provide guidance to permit applicants and local governments on siting and designing projects to minimize impacts from flooding. The Commission's authority in the shoreline band to require changes in the siting and design of a project is limited to addressing impacts to present or future public access or the use of a priority use area for its designated purpose.

The Public Trust Doctrine and Takings. The public trust doctrine establishes a "public easement" over tidal and submerged lands that provides the public with rights to those lands for certain uses. The extent to which those public rights extend inland as sea level rises directly impacts how the Commission makes future regulatory decisions. The Commission's legal staff prepared a report to the Commission on the implications of rising sea levels on its public trust responsibilities and the relative role of "takings." The information below is summarized from the draft report.

The public trust doctrine dates back to Roman times and was imported to America from English common law. Traditionally, the public trust doctrine guaranteed public rights to navigable waters and submerged lands only for certain uses: fishing, navigation and commerce. Over time, each state developed and expanded its own public trust doctrine and the kinds of uses it protects. Through legislation and court decisions in California and other states the doctrine has expanded to include recreational uses and the preservation of lands in their natural state. Uses inconsistent with the public trust (non trust-related uses), are generally those that do not require waterfront locations like residential and non water-related commercial office uses.

The McAteer-Petris Act confers upon BCDC the authority to require “maximum feasible public access,” ensure that public benefits of projects clearly exceed public detriments, and preserve water-oriented uses. These statutory provisions are direct expressions of the public trust doctrine.

A key element of the public trust doctrine is its effect on the regulation of private property. Government must compensate property owners under the Fifth Amendment of the U.S. Constitution if it “takes” private property for public uses. The “takings clause” limits the regulation of private property to protect natural resources and prevent environmental harm. However, the courts have held that government actions to enforce common law public easements such as the public trust doctrine, may be insulated from Fifth Amendment takings claims.

Government can take private property for a public purpose, such as a highway or public works project, through eminent domain or condemnation, or physical occupation when the property owner is compensated for the los of value of the property. An agency that regulates private property, like the Commission, is more likely to confront a “regulatory” taking when its permit decisions reduce allowable uses or diminish the value of property. However, the courts have been unable to establish a set formula to determine when a taking occurs.

In summary, within the Commission’s Bay, certain waterway, salt pond, and managed wetland jurisdiction, the Commission has clear, but, limited authority to address climate change, sea level rise and related impacts for projects that involve the placement of fill in all waters within the Commission’s jurisdiction, including salt ponds and managed wetlands. This authority includes the ability to condition projects to be adaptable to sea level rise. For shoreline protection projects that involve Bay fill, the Commission has the authority to ensure that the fill is placed in a manner that minimizes harmful effects to the environment, which includes harmful effects from future flooding and harmful effects to waters within the Commission’s jurisdiction.

Within the 100-foot shoreline band, the Commission’s authority is limited to the provision of public access and the designation of priority use areas. This limitation is a significant governance vulnerability because it prevents the Commission from ensuring that development on the shoreline is sited and designed to avoid or minimize impacts from future flooding. The Commission does have an important advisory role to make recommendations on the siting and design of shoreline development to protect Bay resources and promote the wise development of the Bay shoreline.

BCDC's laws and policies create two other governance vulnerabilities. First, the Commission implements its authority on a permit-by-permit basis, and has little means of analyzing and addressing cumulative impacts of individual projects, such as shoreline protection. Second, the focus of the McAteer-Petris Act and the Bay Plan on preventing the Bay from getting smaller creates an awkward policy framework from which to build a set of comprehensive climate change policies that sufficiently address the challenges of an expanding Bay.

The public trust doctrine is based on the historic value that the public has a right of access to the shorelines of navigable waters. The public trust formed the foundation for the McAteer-Petris Act and it is the background principle that can enable a number of adaptation strategies. In exercising the public trust, regulatory agencies must act carefully to avoid "taking" the rights of private property owners under the Fifth Amendment. There is no clear test to determine the extent to which a "public easement" can move inland as sea level rises without "taking" private property. This uncertainty about the migration of the public easement could limit the Commission's ability to adopt and implement policies that ensure long-term provision of shoreline public access.

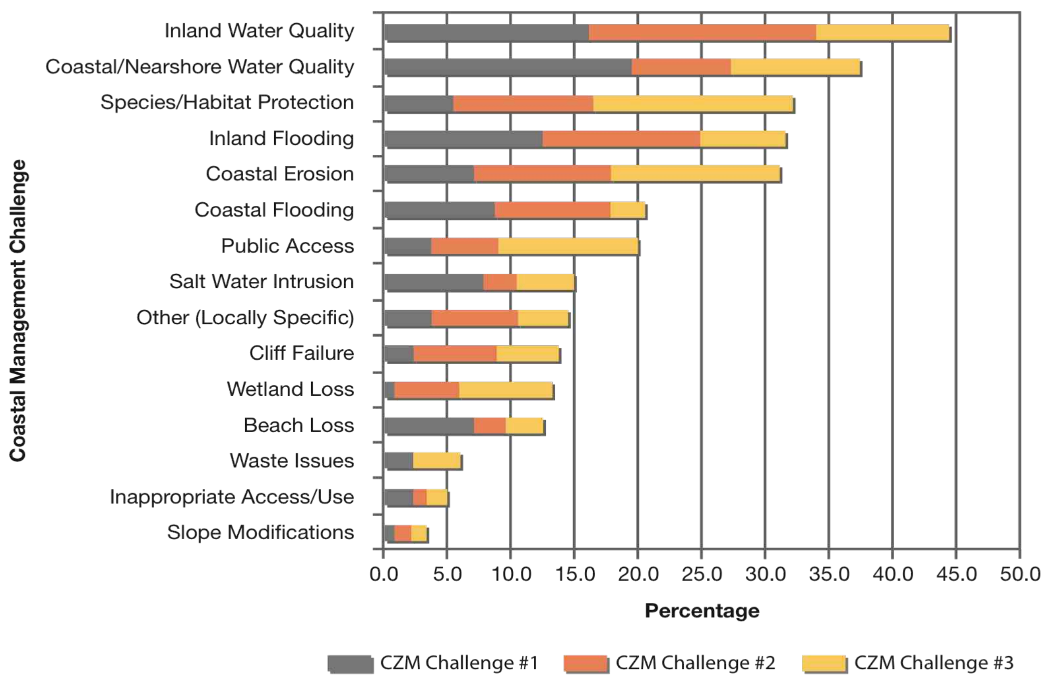
Needs Assessment for Local Jurisdictions

Local jurisdictions shoulder much of the responsibility for land use planning, flood management, water quality protection, and wastewater treatment, all of which will be affected by the Bay-related impacts of climate change. Cities and counties are granted "police powers" by the state, which allow them to protect the overall well-being of their communities (lives, health, and property) by enacting and enforcing ordinances and regulations. The state requires cities and counties to prepare and adopt comprehensive General Plans, consistent with state law, for physical development within their respective jurisdictions. In order to engage in effective adaptation planning, each local jurisdiction needs some level of knowledge about climate change that can be incorporated into ordinances, regulations and General Plans.

Statewide Survey. In 2006, the National Center for Atmospheric Research (NCAR) conducted a survey of local coastal managers in California in order to assess their information needs and their capacity to develop adaptation strategies. NCAR surveyed 299 municipal and county governments on the open coast and along the Bay shoreline. One of the key findings of the study was that coastal managers are already dealing with impacts of climate change. Eight of the top fifteen current challenges identified by coastal mangers can "directly or indirectly be related to climate variability and/or sea level rise (Moser and Tribia 2007(a))" (Figure 4.1).

Figure 4.1 Top Coastal Zone Management Challenges

Source: Moser and Tribbia 2007a



In the NCAR survey of local coastal managers, the topics that were assessed included, but were not limited to: level of knowledge of climate change impacts on coastal zones; information use and information needs related to coastal decision-making; and perceived barriers to adapt to climate change. Major findings from the NCAR study pertain directly to information needs and barriers to taking action:

- **Staffing and Resources.** Staffing is a major barrier to gathering and identifying climate change information. When asked to identify barriers to planning for climate change, 74 percent of respondents cited insufficient staff resources to analyze information; 60 percent identified lack of staff time to gather information and begin getting informed, and 46 percent mentioned lack of technical assistance from state or federal agencies (Moser and Tribia 2007a).

- **Information Accessibility and Relevance.** Vulnerability assessments are key to planning for climate change. Assistance in determining what is most at risk is a priority, especially "locally or regionally specific projections of particular changes in climate….[S]cientific information, even if uncertain, needs to be translated into management relevant variables or metrics (Moser and Tribbia 2007b)." While flooding scenarios are important, a permit analyst deals with rates of shoreline erosion, usually on a project-by-project basis. Projections are needed for timeframes that are relative to the life of a proposed project.
- **Information Location and Format.** For scientific information to be easily accessible and useful to local coastal managers, it should be processed into formats that are used by planners and permit analysts. (Moser and Tribia 2007b).

Although there are some differences in the issues encountered by coastal managers on the open coast and in the San Francisco estuary, qualitative data from a regional summit and a series of interviews conducted by BCDC are generally consistent with the NCAR findings.

In 2006, the Bay Area Air Quality Management District (Air District) hosted a regional climate change summit during which local jurisdictions identified areas where they need assistance. Although the discussion focused on greenhouse gas reductions, elements of the discussion provide important data regarding Bay Area local jurisdictions. Following the summit, the Air District staff identified needs and barriers common to Bay Area governments.

Similar to the findings discussed above, participants cited lack of knowledge as a barrier to confronting climate change and identified a specific desire for improving information accessibility through centralized information storage, such as a climate information clearinghouse or web portal. Participants also asked for guidelines for implementing climate change programs, such as sample ordinances. Participants identified lack of resources and competing internal priorities as major barriers to confronting climate change.

The data from the statewide survey and the Air District's summary of regional needs (BAAQMD 2006), provided BCDC with enough data to proceed with targeted, structured interviews with individuals from local jurisdictions (counties, cities, water districts, flood control districts, water quality agencies, and resource agencies). The purpose of the interviews was to assess common needs of local planners and resource managers within the Bay Area. BCDC's objectives in conducting additional interviews were to supplement and refine the existing data. Rather than replicate work that had already been completed, BCDC performed a qualitative analysis to integrate the existing data and apply lessons learned on the statewide level to the Bay Area.

Other common themes emerged from the interviews. A consistent comment was a request for a comprehensive regional model or set of projections of climate change impacts. The NCAR finding regarding the need for relevant information in a usable format was further echoed in the interviews. All three of these surveys of climate change planning at the local and regional levels concluded that planners and resource managers need better access to information. They would like to be able to turn to a web clearinghouse, or portal, for up-to-date information and downloads. Most interview participants want processed data in the form of GIS shapefiles or policy guidance documents. Only a few prefer unprocessed data that they can incorporate into in-house models. Regardless, a web portal seems to be a preferred distribution method.

The interviews further revealed distinctions between two types of local planners and resource managers: (1) local government land use planning departments; and (2) resource-based coastal managers, such as staff of flood control districts, water districts, water treatment facilities, and resource agencies. Local government land use planning departments were typically less knowledgeable about the Bay-related impacts of climate change than those in the second group or type. They were more likely than group two participants to identify their primary barrier as lack of financial resources and staff. The agencies they rely on for assistance and information were most often cited as the Federal Emergency Management Agency and the Army Corps of Engineers. Besides the obvious bias of being the interviewer and author, it is worth noting that BCDC was cited by almost all participants.

Utilities and others in the second group possessed a greater understanding of Bay-related impacts, especially pertaining to their individual purposes (e.g., water delivery, water treatment, etc.). The most commonly identified barrier was a lack of regional or site-specific information. Group two participants commonly rely on consultants to gather information or produce site-specific analysis.

Other governance vulnerabilities to climate change impacts exist because local governments operate within a policy environment that fails to provide incentives to proactively change their approaches to shoreline development. For example, Proposition 13 has forced local governments to rely more on new development for revenues from development fees and sales taxes, thus creating a fiscal disincentive to limit new shoreline development. Even where financial and policy incentives do encourage planning to improve disaster preparedness and mitigate the impacts of hazards, such as storm flooding, local governments are not required to consider future scenarios of climate change impacts in their planning efforts.

Summary and Conclusions

The Bay Area faces a range of vulnerabilities in its systems of Governance that are evaluated here and summarized in Table 4.1. Governance vulnerabilities reduce the region's ability to adapt to sea level rise and other climate change impacts on the Bay and shoreline. A look at the region's overall governance system suggests that existing challenges to regional planning caused by the patchwork of federal, state, regional and local government authorities in the Bay region will be exacerbated by climate change impacts.

Table 4.1 Summary of Vulnerabilities in Bay Area Governance Systems

Governance	Current and Expected Challenges	Projected Climate Change Impacts	Vulnerability Assessment		
			Degree of Sensitivity	Adaptive Capacity	Vulnerability
BCDC	Limited jurisdiction and authority on the shoreline. Limited ability to address cumulative impacts through permit authority.	Inability to effectively address sea level rise and flooding in permits and planning efforts due to focus on preventing fill, and limited authority to deny permits on the shoreline. Uncertainty about changes to public easement due to sea level rise.	High – Bay and (most) shoreline projects designed to address sea level rise and flooding will require BCDC permit.	Low/Medium – Amendment of Bay Plan policies within existing law and policy framework can marginally improve BCDC's capacity to address sea level rise and flooding in some permits.	High
Local Governments	Already operating at capacity in terms of staff and funding resources.	Additional demands for staff and funding resources. Lack of information about impacts and guidance on adaptation planning.	High – Local governments will have major responsibilities for adaptation.	Medium – Have authority for conducting community adaptation planning, but lack incentives to change approaches to shoreline development.	High
Governance Landscape	Challenges to regional planning and implementa-tion of regional plans caused by patchwork of government agencies' authorities in the Bay Area.	Need for flexible and adaptive regional adaptation planning and management will be challenged by the patchwork of authority.	Medium – Adaptation requires coordinated regional planning and implementa-tion.	Medium - Region will be able to draw on experience from past regional planning efforts, but complexities of climate change create new, unfamiliar planning challenges.	Medium

BCDC faces governance vulnerabilities in its laws and policies. The Commission's jurisdiction on the shoreline is limited to 100 feet from the Mean High Tide Line and within this area BCDC's authority is limited to requiring maximum feasible public access and consistency with priority use areas. The Commission's law is based on principles in the Public Trust Doctrine, and the extent to which the public easement established by the Public Trust can move inland without taking private property is undetermined. Furthermore, because BCDC implements its authority on a permit-by-permit basis, the Commission is limited in its ability to address the cumulative impacts of individual shoreline protection projects. The existing framework of BCDC's laws and policies that focus on preventing the Bay from shrinking is an overarching constraint to the Commission's ability to effectively plan for and adapt to climate change impacts.

Local governments and other management agencies, especially in cities and counties, have broad authority over shoreline land use. However, they lack policy incentives, resources and regional guidance for addressing climate change impacts in land use planning. To address these gaps, local governments need information about the Bay-related impacts of climate change that is region-specific and site-specific. The information should include a regional model that projects 50-100 years into the future or the expected "life of a project." The projections should be developed through a public, inclusive process in order to be widely accepted and used throughout the region. The system most commonly used by local governments for analyzing information is GIS. However, local planners and resource managers can benefit from guidance documents, such as sample ordinances.

Lack of staff and adequate financial resources are the primary barriers to planning for coastal impacts of climate change, both statewide and in the Bay Area. Any assistance to local governments and public management agencies must address this issue either by providing more staff and financial resources or by providing information that is easily integrated into existing operations, planning tools, guidance documents, and planning processes (e.g., General Plan updates).

CHAPTER 5
ADAPTATION STRATEGIES

San Francisco Bay and the shoreline stand to lose critical regional assets from sea level rise––losses that could endanger the public, cripple the economy and eliminate natural resources. The area that is vulnerable to sea level rise is expansive and holds some of the most highly valued development in the state. With an overwhelming 50 percent of the potentially vulnerable areas developed as residential, lives may be at risk due to flooding during extreme storm events.

San Francisco Bay, the shoreline, and the government institutions that manage them, currently face multiple challenges. The San Francisco Bay ecosystem is already stressed by losses in critical estuarine functions, loss of habitat extent, and compromised water quality. The heavily developed Bay shoreline supports multiple, competing uses, including residential, commercial, industrial, and recreational uses. The shoreline is low-lying and occupied by major cities, job centers, and much of the Bay Area's aging and congested transportation infrastructure, on which commuters and regional goods movement depend. In addition, numerous government agencies create a patchwork of authority that is confusing and requires a strong, but flexible network of partnerships. Meanwhile local governments are operating at capacity and lack adequate funding to manage current challenges. Consequently, the current ecosystem, built environment, and governmental systems are not resilient and adaptable to change.

This chapter presents strategies that can increase adaptive capacity of the Bay ecosystem and built shoreline environment by promoting sustainable estuary and shoreline management, resilient and adaptable shorelines and communities, and effective governance in the face of change. This chapter also presents suggested practices for creating institutional flexibility and broadening agency collaboration.

Adaptation Planning Challenges

Climate change adaptation planning poses several challenges. Adaptation planners must convince the public and colleagues that climate change is real and needs to be addressed now, and that adapting to climate change does not disregard the need for mitigation planning nor does it imply any abandonment of hope that mitigation efforts will successfully reduce global warming. Other challenges are the nascent state of the practice of adaptation planning, the dearth of tested adaptation strategies and the uncertainty about the degree and timing of impacts – particularly sea level rise – and the confounding effects of so many impacts. Due to the limited resources available to local governments, climate change planning needs to be "mainstreamed" into existing planning efforts to be implemented effectively (Luers and Moser 2006, USEPA 2008, Moser and Tribbia 2007). Furthermore, mitigation and adaptation planning should be integrated to maximize their effectiveness and avoid inefficiencies or potential conflicts.

Although mitigation measures to reduce global warming remain the dominant focus of climate change planning, recognition that global warming is already occurring has increased awareness of the need to adapt. Nevertheless, mitigation and adaptation remain on separate paths. Integrating mitigation and adaptation in research and policy increases the potential for more cost effective policy that provides greater protection (Wilbanks 2005). The differences in the foci between mitigation and adaptation present some challenges for integration (Wilbanks 2005). The need for mitigation is immediate and our actions must be swift and effective. Adaptation requires planning for longer timescales, using projections that range between 20 to 100 years. Emissions can be quantified, which makes measuring the success of mitigation relatively straightforward. Measuring the success of an adaptation strategy could take 70 years or more and requires development of a method for monitoring success (Wilbanks 2005).

Governments that are already working at capacity and developing mitigation inventories will find it difficult to add the development of adaptation strategies to their workload (BCDC 2007, Moser and Tribbia 2007). Integrating mitigation and adaptation should not be undertaken as one additional task. Rather, determining whether an adaptation strategy decreases or increases the need for mitigation should be a high priority (Wilbanks 2005). For example, conserving and restoring tidal marsh provides flood protection and accentuates mitigation by sequestering carbon. Another example is priority development areas, which provide GHG reductions by reducing driving. Siting such development outside of current and future floodplains is one means of making them adaptive to sea level rise.

Proactive approaches to adaptation have great potential to reduce the social and financial costs of climate change. Some adaptation strategies can readily be integrated into current planning efforts, such as strategies that are needed to address current climate conditions and may provide current social or environmental benefits, but will also have value as protection against future climate change (often called "no regrets" strategies) (Luers and Moser 2006). Examples of these strategies include restoration of tidal marshes and implementing the FOCUS program to achieve compact land use patterns for the Bay Area. Other strategies ("low regrets") involve actions to address future climate change that are incorporated into routine projects, such as repair and maintenance projects, without incurring substantial additional costs at the time of the upgrade (Luers and Moser 2006). To the extent that these strategies can be identified, they should be implemented immediately—an approach that market forces are likely to advance.

Adaptation planning and implementation must be iterative. This requires careful planning, which takes time, financial resources, and sound science-based decisions. The potential for rapid environmental changes creates pressure to act immediately, while the perceived time before climate impacts will arrive may dull interest in acting. Although advances in science have led to better climate change projections, there is still an ample degree of uncertainty. Science will continue to develop at a rapid rate requiring planners and resource managers to create flexible management strategies and stay informed. Environmental changes will be rapid and climate change effects will interact in ways that are unpredictable and lead to unexpected events (Dettinger and Culbertson 2008). However, acting without the necessary time and thought may only result in maladaptation—a situation that will increase costs and reduce benefits to society and the environment as we struggle to undo a strategy that turns out to be maladaptive. Therefore, it is imperative that the potential for rapid environmental change and unexpected events does not propel planners and resource managers into

Box 5.1 Adaptive Management in the South Bay Salt Pond Restoration Project

Adaptive management is a widely recognized approach to addressing uncertainty in resource management. It is often characterized as "learning by doing." An adaptive management approach takes account of uncertainty in the design and implementation of resource management policy and maximizes the opportunity to learn from management actions. Monitoring the success of our management actions in both the Bay ecosystem and along the natural and built shoreline is the fundamental process for reducing uncertainty and implementing effective management. The adaptive management process links values, science, and managers in the decision-making process and throughout project implementation.

The South Bay Salt Pond Restoration Project (Project) is based on an Adaptive Management Plan (Plan). The Plan creates a framework for achieving project objectives through learning from restoration and management actions by monitoring restoration progress and gradually reducing scientific and social uncertainties.

The Project's goal is to restore and enhance over 15,000 acres (23 square miles) of wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation. The Project seeks a balance between restoring wetland habitat and maintaining existing pond habitat, with alternative scenarios ranging from 50 percent each of wetlands and ponds to 90 percent wetlands and 10 percent ponds. Project participants identified eight key uncertainties that could make meeting the project objectives difficult. These included sediment dynamics, bird response to changing habitats, non-avian species responses, mercury issues, invasive and non-native species, water quality, public access and wildlife, and social dynamics. The overarching uncertainty of global climate change is incorporated, de facto, into each of the specific key uncertainties.

The Project participants agreed that, due to the many uncertainties, the mix of habitats that will optimally meet the project objectives—including the amount of tidal restoration and its location—cannot be predicted at this time. Therefore, the project will be implemented and evaluated in phases and will use adaptive management as the process for determining how far the system can move toward full tidal action and associated tidal habitats, while still meeting the project objectives (Trulio et al. 2007).

hasty strategies. Rather, adaptation planning should establish a framework upon which to build as science advances, environments change, and lessons are learned from successes and failures. An adaptive management approach can achieve this (Box 5.1).

Vulnerability Analysis

A vulnerability analysis is the first and most important adaptation strategy. Effective adaptation strategies cannot be identified without first understanding the vulnerabilities they will address. In this report, a vulnerability analysis was conducted to understand the effects of climate change on San Francisco Bay and the shoreline. This effort began with identifying three systems that sufficiently encompass the broad scope climate change planning considerations: the shoreline environment, the Bay ecosystem, and governance. Although this is a false division (especially since future sea level rise presents the ultimate example of a moving shoreline), it provides manageable areas of analysis.

Current challenges (or stressors) to each system affect how resilient and/or adaptive the system can be under scenarios of climate change. Identifying those challenges is an important step in assessing a system's adaptive capacity. Challenges facing each system were identified to provide a qualitative assessment of adaptive capacity and identify where challenges will be exacerbated with climate change. In the discussion on governance, current challenges are identified in terms of the effectiveness of the Commission's jurisdiction and authority and the needs of local governments. The analysis continues with the identification of adaptation strategies and entities with capacity to implement them.

Two climate change scenarios were selected to evaluate the impacts on the Bay and shoreline. Where possible, quantitative analysis was provided to illuminate the scale of the impact, such as the size and population and land areas affected. The scenarios are the closest approximation to a "probability" of occurrence, which is necessary to quantify risks. Throughout the report, it is noted where additional information would provide more robust analysis. The acquisition of or research to generate that information is itself an adaptation strategy. The strategies discussed below grew out of this vulnerability analysis.

Adaptation Strategies

Global temperatures and sea level will continue to rise long after emissions are reduced. Accordingly, some strategies will have long lasting effects, while others will increase resiliency over the next 40-100 years. Both are necessary to sustain shoreline communities and ecosystems. In some instances, strategies that enhance near-term resilience also further the capacity of a system to adapt to long-term impacts of climate change. An ideal short-term strategy or suite of strategies can sustain a system through the next 100 years and prepare the system for a longer-term rise in sea level and temperature.

This discussion begins by exploring shoreline protection strategies that reduce flooding vulnerability for existing development in shoreline communities. Many of the strategies presented here are based on a managed retreat (or managed realignment) approach to protecting upland development while ensuring public safety and available space for tidal marsh migration. Some of the strategies are short-term strategies that make managed retreat more feasible in the long-term. Managed retreat includes strategies that allow flooding or tidal action into areas that are currently dry. In low-lying areas, managed retreat can allow marsh migration into upland areas. Some areas may be unsuitable for marsh migration, but retreat may be necessary for public safety. Managed retreat strategies vary from engineered levee breaches to land use policies that restrict or reduce development in flood prone areas. Generally these strategies provide benefits by reducing the potential for costly storm damage to structures, reducing public safety risks, and providing space for marsh habitat.

The statewide adaptation strategy for the coast and ocean provides some guiding principles for making difficult decisions about maintaining and supporting existing natural features while supporting development through rehabilitation, retrofit, and possibly relocation:

- Protect public heath and safety and critical infrastructure.
- Protect, restore, and enhance ocean and coastal ecosystems, on which our economy and wellbeing depend.
- Plan and design new development and communities so they will be sustainable over the long term in the face of climate change.
- Facilitate adaptation of existing development and communities to reduce their vulnerability to climate change impacts over time.
- Begin now to adapt to the impacts of climate change. We can no longer act as if nothing is changing.

Shoreline Protection. Critical public infrastructure and essential development on the Bay shoreline will require protection to prevent inundation and flooding from sea level rise. For individual projects and regional efforts, difficult decisions will be necessary to determine what to protect and what should not be protected. Extensive analysis will be necessary to determine the appropriate forms of shoreline protection over both the short and long term.

- **Identify Priorities for Protection of Development.** Much of the Bay's shoreline already supports high value development. Some development on the shoreline is vital to the region's economy or provides essential regional services, such as airports, freeways and rail lines, job centers and our neighborhoods. Structural shoreline protection that can withstand more intense storms will become more expensive to install, particularly if engineering standards are changed and raw materials increase in cost. The cost of protecting all shoreline development may be too high. A regional dialogue with stakeholder involvement is necessary to set regional priorities for protection of our communities' critical infrastructure. The task sounds daunting, but for over 60 years, the Bay Area has pioneered regional action regarding difficult decisions and environmental hazards (Box 5.2).

- **Methods of Protection.** It will be necessary to protect certain locations with hard shoreline protection structures (e.g., seawalls) in the short term, while soft, sustainable solutions are evaluated (e.g., wetland restoration). In deciding where to use hard shoreline protection structures, it will be important to recognize and take into consideration the costs and

Box 5.2 Regional Problems, Regional Solutions: A History of Regional Action on Public Safety and Environmental Issues in the Bay Area.

The Bay Area Air Quality Management Districts' website describes how the region came together to address poor air quality (http://www.baaqmd.gov/50th/index.html). When America's fighting forces came home from World War II, many settled in the last place they saw before going overseas--California's embarkation ports. Here, they went to school on the GI Bill, married, bought homes, and began the biggest "baby boom" the world has ever seen. With this population growth came expanding urban areas, shrinking agricultural lands, and the building of housing developments farther from urban centers. For the first time in many years, cars were available, affordable, and now necessary to reach the new suburbs.

The term "smog," originally coined to describe the combination of smoke and fog prevalent in London, soon became a household word in the Bay Area, with open fires from dumps and wrecking yards burning 24 hours a day. Initially measured in levels of eye irritation, air pollution was becoming a major problem, causing significant damage to Bay Area crops.

In 1946, the California Legislature enacted the first air pollution control law authorizing the formation of county air pollution control districts. Los Angeles County opened the first air pollution control office in early 1947 and Santa Clara County followed soon after. However, by 1950, it was evident that pollution overflowed political boundaries, and that a single-county district was not the answer for the Bay Area. In 1955, the Bay Area Air Pollution Control Law was adopted, establishing the Bay Area Air Pollution Control District as the first regional air pollution control agency in the nation.

Alarmed by the fact that between 1850 and 1960 an average of four square miles of the Bay were filled each year, in 1961 citizens in the Bay Area formed the Save San Francisco Bay Association, now called Save the Bay. At the urging of this organization, state legislation--the McAteer-Petris Act--was passed in 1965 to establish the San Francisco Bay Conservation and Development Commission (BCDC) as a temporary state agency. The Commission was charged with preparing a plan for the long-term use of the Bay and regulating development in and around the Bay while the plan was being prepared.

The San Francisco Bay Plan, which was completed in January 1969, includes policies on issues critical to the wise use of the Bay ranging from ports and public access to design and transportation. The Bay Plan also contains maps of the entire Bay which designate shoreline areas that should be reserved for water-related purposes like ports, industry, public recreation, airports, and wildlife refuges.

trade-offs of these approaches. These solutions often lead to additional impacts on the Bay ecosystem and shoreline environment, and, as a result, mitigation requirements for these hard protective structures should be established from the outset. Over time and immediately, where feasible, soft shoreline protection methods should be implemented.

Soft shoreline protection can be integrated with hard shoreline protection to dampen wave energy and maintain tidal wetland function. Tidal wetlands provide valuable flood protection, important habitat, and filter water pollution. The Bay Plan policies on Protection of the Shoreline provide that,

> "[s]horeline protective projects should include provisions for nonstructural methods such as marsh vegetation where feasible. Along shorelines that support marsh vegetation or where marsh establishment has a reasonable chance of success, the Commission should require that the design of authorized protective projects include provisions for establishing marsh and transitional upland vegetation as part of the protective structure, wherever practicable."

- **Compensatory Mitigation.** Static shoreline protection in one area of the Bay, such as a rip-rap revetment or a bulkhead, can increase wetland erosion in other areas of the Bay, thus, further compromising wetland functions and extent (BCDC 1990). The Bay has suffered great loss of tidal marshes in the last century and sea level rise threatens to inundate the remaining wetlands, possibly converting them to shallow or deep-water habitat. Where adverse impacts are unavoidable, mitigation can and should be required to offset the adverse impacts of hard shoreline protection (the term mitigation is used here as an after-the-fact offset of an unavoidable adverse impact as opposed to a preventative action to avoid or lessen the impacts of climate change by reducing GHG emissions).

  Compensatory mitigation for the adverse impacts of shoreline protection on important Bay habitat could be accomplished through a mitigation bank for long-term habitat restoration. BCDC already has policies to guide mitigation banking. The Bay Plan policies on mitigation provide first and foremost that, "[p]rojects should be designed to avoid adverse environmental impacts to Bay natural resources…." However, where mitigation is necessary, the policies further provide that,

  > "[t]o encourage cost effective compensatory mitigation programs, especially to provide mitigation for small fill projects, the Commission may…allow mitigation banking provided that any…resource bank is recognized pursuant to written agreement executed by the Commission. Mitigation bank agreements

should include: (a) financial mechanisms to ensure success of the bank; (b) assignment of responsibility for the ecological success of the bank; (c) scientifically defensible methods for determining the timing and amount of credit withdrawals; and (d) provisions for long-term maintenance, management and protection of the bank site. Mitigation banking should only be considered when no mitigation is practicable on or proximate to the project site."

All forms of shoreline protection should be evaluated to determine the life of the project, the cost, and the cumulative impact on Bay resources. The feasibility of using wetland or other natural, soft shoreline protection alternatives should be determined before using hard, engineered shoreline protection devices. In cases where hard shoreline protection is necessary, a mitigation bank for shoreline protection projects that would have unavoidable adverse environmental impacts is allowable under the Commission's policies. The bank could provide restoration opportunities to compensate for the impacts of hard shoreline protection. Alternatively, the Commission's policies also allow fee-based mitigation when other compensatory mitigation measures are infeasible.

Flood Zone Overlay. The sea level rise data developed by USGS can be used to designate a flood zone where, to protect public safety, public health, and ecosystem functions, specific actions could apply. For example, the zone could prescribe regulatory and incentive-based planning approaches such as, rolling easements, density restrictions, and clustered development, property acquisition, or purchase of development rights. Regulatory tools such as those described below have potential to limit development, provide notice to property owners that their property is at risk, and preserve open space and public benefits. With the exception of the public access strategy, BCDC does not have the authority to undertake these strategies to reduce the impacts of flooding. However, BCDC does have a regional perspective and expertise to assist local governments in developing future flood zones and strategies to reduce impacts within those zones.

In some cases, other agencies and organizations have authority and/or ability to implement these suggested strategies. For example, a local government can effect clustered development through its zoning authority. Other strategies would require action by the state legislature or Congress to establish needed legal authority or requirements for implementation.

- **Clustered Development.** One type of open space zoning is clustered development, which only allows development in one area of a parcel. Where parcels are adjacent, sometimes development is clustered near adjacent property lines to maximize open space within a few parcels. Under this strategy, development would be allowed in flood zones, but strategically located back from the shoreline to provide space for the shoreline to move.

- **Rolling Easements.** The concept of rolling easements comes from the Texas Open Beaches Act, which establishes a "rolling easement" over all lands seaward of the first natural line of vegetation. The Act authorizes the State to enforce a public access easement over the dry sandy beach from the mean high tide line to the first line of natural vegetation, and to petition the courts to remove any encroachments on a public beach. The easement expands or "rolls" with the natural migration of the beach vegetation line.

  The earlier discussion of the public trust (Chapter 4) established that in California public trust rights extend to the Mean High Tide Line. In Texas, the Public Trust rights to the dry sandy beach are guaranteed under Texas common law. The trust easement is a background principle of property law, and therefore the property owners do not have a right to exclude the public seaward of the first line of natural vegetation (BCDC 2009).

  If California common law contained similar background principles, legislation could establish a rolling easement over all coastal or bay front land. Another approach would be to purchase a property right to take possession of privately owned land if the sea rises a certain amount, or require a deed restriction to acknowledge that the public trust migrates inland to the mean high tide level with sea level rise (BCDC 2009).

- **Purchase of Development Rights.** A purchase of Development Rights (PDR) program is usually a voluntary program in which landowners sell the development rights of their land to a nonprofit land trust or other organization, or a public agency. Landowners can sell development rights just as they sell mineral rights or water rights. Once the development rights are sold, the right to develop or subdivide that land is permanently relinquished. All other rights and responsibilities associated with the land are retained by the landowner (Gathering Waters Conservancy).

  Relinquishing the development rights is similar to having a conservation easement on the property. To establish the value of the development rights, the estimated sale price of the property with a conservation easement is subtracted from the current market value of the property with its development rights (Western Governors' Association 2001).

- **Flood Insurance Program.** The National Flood Insurance Program (NFIP), under the direction of the Federal Emergency Management Agency (FEMA), provides insurance in floodplains, addresses floodplain management and flood hazard mapping. The NFIP was established to improve recovery after a flood. However, NFIP insurance is provided at subsidized rates, effectively encouraging development in floodplains and opening new areas to investment (Levina et. al. 2007). The NFIP provides incentives to local governments through the Community Rating System. Local governments can receive higher ratings for practicing "good" floodplain management. For example, higher ratings are awarded for implementing building codes that provide flood protection and for requiring that development sites are elevated. The reward for higher ratings is even lower insurance rates for their residents, which can further encourage development in floodplains. Furthermore, the mapping component of the NFIP is based on historic flooding rather than scenarios of future sea level rise. The NFIP in the Bay Area is developing a program to map future sea level rise scenarios. Insurance for development that is vulnerable to future sea level rise should be phased out.
- **Financial Incentives and Disincentives.** The Nation's coastal barrier islands support richly diverse ecosystems. Their warm sunny beaches also attract a booming tourist industry and rapid development, which has had detrimental impacts on the ecosystems. The barrier islands are particularly vulnerable to erosion from storm surge and flooding. Frequent extreme weather events pose a public safety threat and cost billions of dollars annually (Vaughn 2007). The federal Coastal Barrier Resources Act (CBRA) is a statutory initiative to increase public safety, minimize waste of federal resources, and protect the ecological integrity of the Coastal Barrier Resources System (CBRS) by discouraging development within the CBRS (Vaughn 2007). The CBRS originally extended to 400 barrier islands along 2,700 miles from Maine to the Texas Gulf Coast (452,834 acres or 707 square miles) and was later amended to expand the CBRS by an additional 820,000 acres (1253 square miles) of coastal wetlands and nearshore waters. By expanding the definition of CBRS to include other types of coastal landforms, the Florida Keys and barrier islands in the Great Lakes were included (Vaughn 2007).

  The CBRA restricts federal flood insurance and federal funding for roads, sewers, or other kinds of infrastructure on barrier islands or portions of some barrier islands. Development is not prohibited, but rather, in theory, a disincentive to develop is established due to the lack of federal financial support. A 2002 U.S. Fish and Wildlife Service study of the CBRA's effectiveness found that higher-income developments within the CBRS occurred at the same rate as nearby areas not included in the CBRS

(Vaughn 2007). Other studies indicate that some slowing of development has occurred within other areas of the CBRS. However, where real estate values or rent from tourists is high enough, the economic incentives to build outweigh the federal disincentives.

The amendment to the CBRA that expanded the definition of CBRS also required the Department of Interior to map areas along the Pacific Coast that could be eligible for inclusion in the CBRS (Vaughn 2007).

- **Social Equity Study and Financial Assistance Programs.** Although BCDC has no authority to address social equity issues, the social equity analysis in this report highlights the need for further study of the significant impacts to low-income communities. The risk of shoreline flooding as well as actual flooding from sea level rise and related storm activity will impact communities differently. Those who have fewer resources at their disposal will have a more difficult time relocating or enduring interruptions in services. The region must be prepared with assistance programs to those most in need. Measures to include low-income communities in regional decision-making should be identified and implemented. Most importantly, a regional analysis of social equity issues related to sea level rise is needed. The analysis should look at low-income communities at risk of flooding or adjacent to future flood zones and should recommend measures to prepare for and/or retreat from flood zones. Social-equity, environmental justice organizations and public agencies are already working on climate change mitigation and other measures to reduce climate change impacts to and increase resilience of low-income communities. The risks and impacts associated with sea level rise must be a component of these efforts. Beginning to address the issue now allows more time to adapt in the future.

- **Public Access.** A 16-inch rise in sea level will flood over 400 public access sites, or approximately 57 percent of the public access around the Bay. Over 616 public access sites, approximately 87 percent, are located in areas vulnerable to a 55-inch increase in sea level rise. Periodic and consistent flooding can increase damage to public access areas, which can then require additional fill to repair, raise maintenance costs, and cause greater disturbance and displacement of the site's natural resources. Risks to public health and safety from sea level rise and shoreline flooding may require new shoreline protection to be installed or existing shoreline protection to be modified, which may impede physical and visual access to the Bay. The McAteer-Petris Act allows BCDC to deny a permit in the 100-foot shoreline band only if it "fails to provide maximum feasible public access, consistent with the projects, to the bay and its shoreline."

Therefore, in the 100-foot shoreline band, the Commission can only address the impacts of sea level rise on public access to the Bay and the shoreline. Access to the shoreline is one of the many features that enhance quality of life in the Bay Area and foster an appreciation of the Bay. Therefore, the Commission should require that public access is sited, designed and managed to avoid significant adverse impacts from sea level rise and shoreline flooding and require that the legal document which guarantees the public access accounts for future changes from sea level rise. The Commission could, for example, require any of the following:

1. Require public access to be constructed to accommodate projected sea level rise. Designing public access to accommodate sea level rise could involve allowing regular flooding of the landscaped areas within public access areas, but ensuring that pathways are elevated high enough to avoid flooding.
2. Require new access to be provided if existing access areas are permanently inundated.
3. Deny a permit for development that would destroy or harm public access.
4. Require in lieu access of the payment of fees to mitigate the loss of public access area as sea level rises and storm impacts increase.
5. Require that projects are set back far enough from the shoreline to retain space for public access as sea level rises (within the limits of the 100-foot shoreline band).

Protecting the Bay. Further inundation of tidal habitat is potentially devastating to the San Francisco Bay ecosystem. During accelerated sea level rise, adequate sediment supply can prevent erosion of tidal flats and help maintain inter-tidal elevations, suitable for plant growth and survival in restored and ancient tidal marshes of the Bay. However, even with sedimentation, buffer zones of low-lying open space are necessary to avoid loss of transitional, upland habitats while allowing tidal habitats to migrate or transgress landward.

The loss of transitional habitats, such as the upland ecotone, to erosion or inundation will likely devastate a diverse number of species, including California clapper rail and the salt marsh harvest mouse who use these habitats for refuge during high tides. Buffer zones could preserve corridors of habitat for species to migrate from upland watersheds to the Bay shoreline. These corridors also could help avoid future conflicts between human development patterns and the Bay ecosystem, while conserving a range of species throughout the food chain.

Currently, there are few such buffer zones due to development. Upland areas to which tidal wetlands can transgress must be identified and property ownership should be documented so that institutions can begin the process of protecting these lands. Protecting upland and transitional habitats provides immediate benefit by offsetting previous loss and fragmentation of Bay habitats. In the near-term, undeveloped lands upland of tidal marshes provide a buffer to the negative impacts of sea level rise while providing habitat. Over the long-term, as sea level rises, these lands allow migration and reduce the likely loss of biodiversity.

The tools required to identify migration areas and document property ownership are already available to the Commission. The Commission's laws and policies do not preclude the identification of available uplands and property ownership for future uses as buffers and transition zones. The Commission has clear authority in the Bay over wetland restoration activities, dredging, and sediment management. Where buffer zones are located entirely on the shoreline, the Commission cannot condition a permit to require them. However, the Commission can encourage buffer zones.

- **Restore Wetlands.** Wetlands are necessary for the health and functioning of the Bay. The depletion of wetlands and, hence, loss of their important ecosystem services is one of the primary stressors on the Bay ecosystem and when a system is under stress, it is less resilient and its adaptive capacity is reduced. Restoring wetlands is necessary to improve ecosystem functions today and sustain the ecosystem into the future.

- **Prioritize Wetland Restoration.** In the late 1990s, Bay Area scientists, government representatives, nonprofit organizations, and members of the public worked together to establish habitat goals for the tidal wetlands, or Baylands, of the San Francisco Bay. Through this collaborative process, goals for tidal marsh restoration were established that guide restoration practices and monitoring activities. Sea level rise was not factored into these goals.

  The Baylands Habitat Goals Project did not consider future sea level rise, and the impact of future sea level rise on tidal marsh extent, including those planned for restoration, is significant. Tidal wetland restoration projects should be prioritized regionwide to minimize restoration efforts that are not adaptable. A regional effort to update the Habitat Goals report could accomplish this. However, the initial habitat goals effort was substantial, involving significant outreach and coordination efforts among various agencies, scientists, and other stakeholders. A smaller, adjunct process, involving the participants from the initial process could accomplish this task.

  This task would require additional time and resources, but would yield immediate savings by strategically targeting near-term restoration efforts that are not likely to adapt to future sea level rise.

- **Create Buffer Zones.** Tidal wetland restoration projects are reviewed by a number of agencies with permit authority in the Bay. Although there are currently three active landscape-level restoration projects—the South Bay Salt Pond Project, the Hamilton/Bel Marin Keys Project and the Napa Salt Pond Project—most proposed restoration projects are typically designed to fit a particular site over which the project proponent has ownership or management responsibilities. In such cases, the property boundary determines the extent of habitat restoration and influences the design of project elements. For smaller project areas, it is difficult to incorporate buffer zones and transition habitat while still reaching target acreages for the intended habitat.

  The difficulty increases when the restoration effort results from a wetland mitigation requirement. In this case, the restoration must also meet mitigation requirements (e.g. the Clean Water Act requires 3:1 mitigation for area of wetlands lost). Whether or not a restoration project site is small, the restoration project should analyze whether buffer zones are feasible, and if possible, they should be incorporated into the restoration design. Agencies that are required to enforce mitigation requirements should consider revising laws and policies to include buffer zones in mitigation projects and other strategies for ensuring that mitigation is successful under future sea level rise scenarios.

  For example, the Commission's policies on mitigation provide specific ratios for compensatory mitigation and recommend buffer zones. Mitigation Policy 5 states that,

  > "[t]o increase the potential for the ecological success and long-term sustainability of compensatory mitigation projects, resource restoration should be selected over creation where practicable, and transition zones and buffers should be included in mitigation projects where feasible and appropriate. In addition, mitigation site selection should consider site specific factors that will increase the likelihood of long-term ecological success, such as existing hydrological conditions, soil type, adjacent land uses, and connections to other habitats."

  This forward-thinking policy was updated more recently than the Commission's policies on Tidal Marshes and Tidal Flats, which do not include any provisions for buffers zones. Therefore, the Commission can only require a feasibility analysis of buffer zones for mitigation projects.

- **Regional Sediment Management.** One of the key findings in Chapter 3 on the Bay ecosystem is that managing and maintaining adequate volumes of sediment in the Bay is necessary for marsh sedimentation. Bay sediment dynamics control many estuarine processes, such as locations of tidal flats and marshes, habitat variability, and the productivity of Bay waters. The net flux of sediments into and out of discrete portions of the Bay determines whether erosion or accretion occurs, and creates features such as shoals and channels, and specific habitat environments such as fine-grained or sandy bottoms. High concentrations of suspended sediment can reduce light penetration and lower biological productivity, but can also help prevent harmful blooms of algae. An adequate supply of sediment is needed to maintain the dynamic equilibria of wetlands and tidal flats within the Bay system, while excessive volumes of sediments can silt in channels and reduce open-water habitats.

An understanding of sediment dynamics is particularly important to predicting the impact of sea level rise and global climate change on the Bay. Sediments can feed tidal flats and wetlands to maintain their elevation in the tidal frame while minimizing erosion and inundation. Decreases in local or regional sediment supply can exacerbate erosion and inundation.

A regional sediment management (RSM) approach is necessary to manage sediments within the context of the entire system, including sediment sources, movement and sinks within the system and exchange with the ocean. Application of RSM to the Bay will allow the Commission and other coastal managers to better understand both the impacts of individual permit decisions on the entire system (e.g. dredging and disposal), and also the impacts of systemic processes such as climate change and sea level rise on permitted projects (e.g. success of wetland restoration projects).

RSM would provide both short term and long term ecosystem sustainability. In the short term, RSM would increase resiliency so that the Bay ecosystem is more likely to rebound from changing climate. RSM also has the potential to ensure adequate sediment supply into the future so that ecosystems can adapt to climate change. BCDC has direct authority over dredging. However, the Commission does not require policy guidance to embark on an RSM strategy for managing dredged materials and Commission staff is initiating an RSM study for the Bay.

Regional Coordination and Action. Three years ago the Bay Area Air Quality Management District held its Bay Area Regional Climate Summit, which was the first major effort in the region to bring together a range of diverse interests to address GHG emissions. Within months of the Climate Summit, AB32 was passed by the legislature and signed into law by the Governor. AB32 established emission targets that were clear and quantifiable. There were concerted efforts to identify emissions inventory methods and strategies for reducing GHGs.

Three years later, these mitigation strategies are being incorporated into general plans and regional planning efforts. In the Bay Area, mitigation planning is widely recognized as a necessity of future planning—it is a new element of planning that will continue to evolve and present new challenges.

The Bay Area needs to begin a similar regional dialogue about adaptation in San Francisco Bay and on the shoreline. This is necessary for education about adaptation and acceptance of adaptation strategies for the region. However, adaptation planning is not easily packaged for promotion or integration into existing planning processes. It involves uncertainty, immeasurable outcomes, and the need for flexibility. BCDC hosted a Bay Area Regional Forum on sea level rise that initiated this necessary dialogue. The first steps in developing an adaptation plan for the region are: to recognize that the Bay-related impacts of climate change are regional in scope; and to begin building consensus on regional goals.

- **Comprehensive Regional Planning.** To prevent San Francisco Bay from continuing to get smaller, the Legislature created BCDC and empowered it to exercise regulatory control over development in the Bay. After four decades of existence, BCDC has been accomplishing the public policy goal set out by the Legislature. However, the greatest threat to the Bay Area over the next century is that global climate change will make the Bay larger.

  Under current law, the responsibility for regulating development in areas likely to be flooded by sea level rise rests largely with the nine counties and 46 cities fronting on the Bay. BCDC does not have any planning or permit authority over many areas at risk of inundation. Therefore, BCDC has no authority to prohibit such development or require flood protection measures to protect low-lying areas stretching inland more than 100 feet from the shoreline. While BCDC does have authority to protect valuable tidal marsh habitat in the Bay, it lacks the authority to ensure that tidal marshes will be sustained with rising sea levels. As sea levels rise, marshes must migrate upland or be inundated. BCDC does not have authority to ensure that upland areas are available for marsh migration. Further, BCDC has no legal responsibility for reducing greenhouse gas emissions to slow the rate of sea level rise.

  The region needs a bold, new strategy to meet the challenges of climate change head-on. The goal of this strategy should not be to restore the Bay to historic conditions. Instead, the strategy should describe a vision for resilient communities and adaptable natural areas around a dynamic and changing Bay that will have different sea level elevations, different salinity levels, different species and different chemistry than the Bay has today. The strategy should embrace a pro-active adaptive management strategy aimed at putting conditions in place that can respond in a desired way to changes that will come about in the future as a result of climate change.

This new strategy should draw from the lessons learned during the formulation and implementation of BCDC's existing, highly effective San Francisco Bay Plan, particularly the plan's goal of balancing conservation and development. The new strategy should integrate ecosystem-based adaptive management principles to ensure that future development, shoreline retreat, flood protection and wetland enhancement strategies are coordinated to achieve a vibrant, healthy Bay co-existing with sustainable communities around the Bay.

- **Integration of Mitigation and Adaptation.** Integrating mitigation strategies and adaptation strategies increases efficiency by reducing redundancy and ensuring that mitigation strategies do not cause maladaptation. The regional climate change strategy adopted by the JPC, though largely focused on mitigation, includes both mitigation and adaptation actions. As the Joint Policy Committee moves toward acceptance of adaptation strategies, for example, with the BCDC's work on sea level rise adaptation, the JPC's climate change strategy would benefit from exploring ways to integrate mitigation and adaptation, such as by identifying "win win" strategies. This integration is especially important in the land use and transportation areas of study. As an example of the potential for integration, MTC is currently updating its regional transportation plan (RTP), which includes mitigation measures. As a part of the RTP update, MTC is working with BCDC to identify impacts from sea level rise to transportation infrastructure and develop adaptation strategies.
- **Bay Plan Amendments.** Amend the *San Francisco Bay Plan* to reflect these strategies by: (1) adding a new findings and policies to the plan in a climate change section that applies to all sections of the plan; (2) revise and update the findings and policies in the sections of the Bay Plan on Safety of Fills, Protection of the Shoreline, Tidal Marshes and Tidal Flats, and Public Access.

Funding. The discussion on the needs of local governments identifies two major needs for funding adaptation planning: (1) providing adequate staff and resources to local governments; and (2) providing scientific information that can be incorporated into decision-making.

Throughout the report, it has been noted where more information is necessary. In October 2008, the Commission staff produced a white paper detailing the information that is necessary to continue assessing vulnerability to climate change, which is posted on the Commission's website http://www.bcdc.ca.gov/planning/climate_change/2008-09-24_forum.shtml.

Adaptation Planning Approaches

Planning for the impacts of climate change on the shoreline and in the Bay requires a flexible or iterative planning process that can accommodate rapidly advancing scientific knowledge. Shoreline planning, whether in urban or rural areas, will be increasingly challenging as the line between uplands and Baylands becomes more dynamic, thereby requiring a creative planning approach that is open to crossing ecotones and including the built environment. Working among so many jurisdictions requires substantial efforts to partner to increase efficiency in city and regional planning and resource management. Ecosystem-based management (EBM) is an umbrella for integrating human needs and systems into marine or estuarine environmental management, bringing stakeholders into decision-making processes, and providing direction through those processes. As one approach under an EBM umbrella, watershed management addresses the need to recognize natural ecosystem boundaries and manage ecosystem services within those natural units. EBM also recognizes the need for iterative approaches to managing complex systems and, consequently, marries well with adaptive management. What EBM can provide is a portfolio of approaches and the online tools to support these approaches, ranging from tools for stakeholder outreach to mapping tools.

Summary and Conclusions

Adapting to climate change on the San Francisco Bay shoreline is critical to the region's economic stability, safety and public health. Flooding from sea level rise alone will impact long-term viability of our neighborhoods, job centers, transportation, water and wastewater infrastructure, schools and fire stations and vital ecosystem services on which our quality of life and the regional and state economies depend.

To integrate rapidly advancing scientific knowledge about the impacts of climate change, adaptation planning for the Bay and shoreline must be a flexible and iterative process. Shoreline planning will be increasingly challenging as the line between uplands and Baylands becomes more dynamic, thereby requiring a creative planning approach that integrates both the natural and the built environment. An ecosystem-based, adaptive management approach would integrate the human component of ecosystems into ecosystem management by bringing stakeholders into decision-making processes, promoting interagency collaboration, and providing direction through those processes.

Guidelines being developed in the state's adaptation planning process promise to be helpful in making difficult decisions about protecting the shoreline and dealing with proposed shoreline development in the Bay Area.

Adaptation Strategies. The first and most important adaptation strategy is to conduct a vulnerability analysis. Understanding vulnerability to the extent feasible within the limitations of available science and resources is critical to developing adaptation strategies. Vulnerability occurs over a long timeframe and affects people in the near-term. Therefore, both short-term and long-term adaptation strategies should be identified.

The tables below summarize adaptation strategies for the Bay and shoreline. They rely on the discussion found in this chapter of BCDC's authority pertaining to each group of strategies. They identify whether a strategy is appropriate for the current update to the Bay Plan findings and policies (i.e., can the strategy be applied within BCDC's limited authority and jurisdiction), whether the strategy requires a longer-term planning process, or both. For some strategies, BCDC lacks regulatory authority, but findings and policies that provide guidance relating to these strategies are appropriate for this Bay Plan update.

Shoreline Protection

Strategies	Is this strategy a short-term Bay Plan amendment, a long-term objective, or both?
Identify priorities for protection of development.	Long-term objective
Integrate soft shoreline protection into hard shoreline protection structures whenever feasible.	Both
Provide compensatory mitigation when shoreline protection cannot be avoided and will cause adverse impacts.	Short-term amendment

Develop a flood zone overlay where a variety of adaptation strategies can be used.

Strategies	**Is this strategy a short-term Bay Plan amendment, a long-term objective, or both?**
Clustered development in one area of a parcel.	Long-term objective
Require a sea level rise or rolling easements to accommodate sea level rise.	Long-term objective
Purchase development rights along the shoreline.	Long-term objective
Revise the flood insurance programs.	Long-term objective
Provide financial incentives and disincentives where appropriate.	Long-term objective
Social Equity Study and Financial Assistance Programs.	Long-term objective
Require that public access is sited, designed and managed to avoid significant adverse impacts from sea level rise and shoreline flooding.	Both

Protect the Bay

Strategies	**Is this strategy a short-term Bay Plan amendment, a long-term objective, or both?**
Restore Wetlands.	Both
Prioritize Wetland Restoration.	Long-term objective
Create Buffer Zones for marsh migration.	Both
Engage in Regional Sediment Management.	Both

Regional Coordination and Action

Strategies	**Is this strategy a short-term Bay Plan amendment, a long-term objective, or both?**
Comprehensive Regional Planning for sea level rise in San Francisco Bay and the shoreline.	Long-term objective
Integrate of Mitigation and Adaptation.	Long-term objective
Provide adequate funding to local governments and for research.	Long-term objective

Strategies that the Commission can begin working on immediately should be incorporated into the Bay Plan in the following manner:

1. Create a climate change policy section of the Bay Plan that addresses the following:
    a. Updating sea level rise scenarios and using them in the permitting process;
    b. Developing a long-term strategy to address sea level rise and storm activity and other Bay-related impacts of climate change in a way that protects the shoreline and the Bay; and
    c. Working with the Joint Policy Committee (JPC) and other agencies to integrate regionally mitigation and adaptation strategies and adaptation responses of multiple government agencies, to analyze and support environmental justice issues, and to support research that provides useful climate change information and tools.
2. Amend findings and policies on public access to provide public access that is sited, designed and managed to avoid significant adverse impacts from sea level rise and ensures long-term maintenance of public access areas.
3. Amend findings and policies on tidal marshes and tidal flats to ensure that buffer zones are incorporated into restoration projects where feasible and sediment issues related to sustaining tidal marshes are addressed.
4. Amend the policies on safety of fills by updating the findings and policies on sea level rise and moving them to the new climate change section of the Bay Plan.
5. Amend the policies on shoreline protection to address protection from future flooding.

APPENDIX A
METHODS FOR DEVELOPING DATA

In order to perform the analysis and mapping performed in this report it was necessary to accurately identify areas vulnerable to projected sea level rise. A team led by Noah Knowles, USGS, built a hydrodyamic model to identify areas at risk of inundation under a variety of sea level rise scenarios. In order to identify areas vulnerable to these inundation scenarios it was necessary to assemble the best available elevation data into a regional grid, integrate historic (1996-2007) tidal data and overlay with estimated increases in sea level, 40 and 140 cm.

A regional digital elevation data set was assembled that was comprised of a number of data sources, including LiDAR (Light Detection and Ranging) in the South Bay and in portions of Solano County and Napa County. Additional photogrammetry and satellite based data was assembled to create the regional data set. The data has a horizontal resolution of 2m and nearly all areas have a vertical accuracy of between 10 and 30 cm.

In order to integrate the elevation of the water within the estuary a hydrodynamic model of system was driven by hourly data collected between 1996-2007 at the Golden Gate. This historic data captures the temporal range in tides as well storm based inputs such as storm surge. The model then propagates the fluctuations throughout the Bay and towards the Delta as far east as Mallard Island. The model was verified using tide gage data in various locations throughout the Bay. Based on the historic data, the mean monthly high water was mapped for the Bay at 200 m resolution which corresponds with present day average monthly high water. Finally, the water surface height within the model was modified by 40 cm and 140 cm to integrate Ramstorf's projections. Further verification was performed by comparing water height fields for present day and projected conditions to land elevations (Knowles 2008).

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